Hawaii's Shoreline

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2/ HAWAII'S SHORELINE
Appendix I.

HIG Report No. 41

2a/ COASTAL GEOLOGY OF HAWAII.

By

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~~Hawaii. University. Hawaii Institute~~ Hawaii. Department of Planning & Economic Development

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ABSTRACT

This report of the geology of beaches and coasts of the State of Hawaii has been prepared by the staff of the Hawaii Institute of Geophysics for the State Department of Planning and Economic Development. Included are the results of field work performed under contract since early 1962, and summaries of previous investigations. The report is intended both as a contribution of fundamental scientific information and as the scientific basis for a general shoreline plan being formulated by the Department of Planning and Economic Development.

The geology of all segments of coastline on the islands of Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii is described, and the specific characteristics of the island shorelines have been mapped. Kauai has the longest stretches of good beach, and few areas of serious erosion. Oahu has more coastal plain and reefs, and the greatest urban development in its coastal areas. Oahu's beaches are second only to Kauai's in extent, and are the most-used in the State. The fringing reefs of Molokai and Lanai are being covered with alluvium, and their best beaches are, as is true of most of Hawaii's islands, at their western ends. The beaches north and south of the Isthmus of Maui are undergoing general erosion. Hawaii Island has very few beaches, except at Kawaihae Bay. Niihau was visited only once, and Kahoolawe not at all.

Ninety beaches were selected for observation. These included all those in active use, all others that are large, and some also chosen as being typically representative of other sections of the coast. The hinter-

land, shoreline, and offshore features, the dimensions and seasonal changes of the beaches, and the characteristics of the sand are described and illustrated for these 90 significant beaches during the one and one-half years of field study.

In support of these coasts and beach descriptions there are several studies and summaries of previous investigations of such aspects as coastal geomorphology, sources of energy in the nearshore environment, and sand characteristics. Local beach sand is demonstrated to have formed partly as detritus of lava and other grains eroded from the islands, and partly as fragments of calcareous skeletal parts of shallow-water marine organisms washed ashore by the waves. As a general rule the volcanic content of sand in individual beaches increases to the south and east, both for single islands and for the chain as a whole. Calcareous organisms, in order of contribution to sand, are: foraminifera, mollusks, red algae, echinoids, coral, and green algae. Sand losses are attributed to erosion, transport through channels to deep water, beachrock formation, abrasion, deflation, and man's exploitation.

Tsunami behavior, inundation, and protection are described. Other natural disasters affecting shoreline areas are storms, landslides, earthquakes, and volcanism.

It is recommended that the exploitation of sand be controlled, and that existing beaches be stabilized. State, federal, and University agencies with responsibilities in shoreline research and engineering deserve continued support, and some other lines of research should be continued or initiated, probably under State coordination.

The annotated bibliography includes the most significant articles on nearshore marine processes, tropical sedimentation, and local geology.

It is believed that the chief value of this report is that it is a summary, in one paper and in the language of educated laymen, of the important physical aspects of Hawaii's coastal areas. Certainly the report's weakest feature is the briefness of the period of measurement of beach changes.

INTRODUCTION

History and Scope of the Project

In the spring of 1961 the then State Department of Planning and Research, and now State Department of Planning and Economic Development, proposed to undertake a program of determining the most appropriate use of Hawaii's coastal areas. Mr. F. Lombardi, then Director of the Department, asked Mr. D. C. Cox, Geophysicist in charge of the Tsunami Research Program at the Institute of Geophysics of the University of Hawaii, for his comments on the proposed Hawaii shoreline plan. Mr. Cox pointed out the inadequate state of the knowledge in Hawaii about the physical processes acting near the shoreline.

During the summer and fall of 1961 the Department of Planning and Research negotiated with the University of Hawaii for a contracted investigation, through the Hawaii Institute of Geophysics, of the physical condition of the shoreline areas of the State and of certain related natural processes, such as the origin and transportation of sand. The agreement to a formal contract was made on 11 December 1961. Because of a proposal which he had drawn up previously for a scientific study of some other aspects of beach and shore processes in Hawaii, the writer, Dr. R. Moberly, Jr., was named project director. Dr. F. P. Shepard of Scripps Institution of Oceanography agreed to initiate the field work, and the study was begun upon his arrival in Hawaii on 1 March 1962. Dr. Shepard summarized his observations after four months of field activities (Shepard, 1962; Shepard *et al.*, 1962).

Support for additional periods of field work and laboratory analyses, designed to complement the Planning Department's study, came through a contract between the Harbors Division of the State Department of Transportation and the University of Hawaii. The main purpose of the second investigation was to measure seasonally the beach changes and sand characteristics at 80 selected sites in the State. The data gathered for the State Harbors Division have thus been of great value in preparing this present report of general shoreline characteristics.

The scope of the investigation, as contracted with the Planning Department, has been as follows:

1. Inventory, map, and analyze beaches and coasts.

   The geologic characteristics of shorelines were mapped on sheets provided by the Planning Department, and are discussed in this report. Sand-grain parameters were determined for more than 1000 sand samples, and representative samples from 90 significant beaches are reported herein. Calculations of sand volumes will be reported to the Harbors Division, and copies of that report will be sent to the Planning Department. Beach descriptions include sand composition, grain size and sorting, topographic profile, and history when determined.

2. Inventory, map, and analyze beach material source.

   The general types and abundance of lime-secreting organisms were determined in some shallow-water areas, and their contributions to several score sand samples were determined. Noncarbonate components of beach sands were also determined.

3. Inventory, map, and analyze sand transport and loss.

Wave and other energy sources and nearshore circulation have been determined for most beach systems. The storm and seasonal changes between spring 1962 and the end of summer 1963 are recorded, and, where possible, long-term changes are indicated. Agencies of sand-loss are identified.

Because of three factors which had not been anticipated at the time the contract was signed, this final report has been delayed beyond its due date of 1 October 1963. First, it appeared desirable to incorporate in the report the results of this past field season, chiefly sponsored by the State Harbors Division, and most field aspects did not end until mid-September. Second, a series of unexpected changes occurred in graduate student and Institute staff responsibilities. Third, a three-months' delay in the completion of construction and furnishing of the Institute of Geophysics building on campus resulted in a loss of almost all laboratory and drafting facilities from mid-August to early October.

The design of this report is apparent in the table of contents: a major section on coastal geology for natural segments of coastlines of each island, an illustrated report on each of 90 significant beaches, and a group of supplementary reports, amplifications of methods used, and other miscellaneous aspects of the over-all study.

Acknowledgments

This investigation would not have been possible without the whole-hearted support of a great many people, both as individuals and as representatives of organizations. First, I thank Dr. F. P. Shepard for interrupting a busy schedule to initiate the field studies, in his customarily vigorous fashion, and to outline much of the subsequent activities. Dr. Shepard was ably assisted by Scripps Institution graduate students B. L. Oostdam and H. H. Veeh, and by Mrs. Shepard.

Dr. T. Chamberlain, who assumed charge of subsequent field activities after his arrival as a new University staff member, is to be commended for the success of the field work, which also was injury-free. I am especially grateful to Dr. Chamberlain, my colleague, for council on innumerable occasions in the course of the research. He wrote the section on energy sources in this report. Graduate students in the Department of Geology of the University of Hawaii, who proved to be valuable research assistants in this investigation, were F. W. McCoy, Jr., J. F. Campbell, and G. D. Stice. Mr. McCoy directed some of the laboratory work, assisted in the field work, and wrote the descriptions of beaches on Molokai, Lanai, Maui, and Hawaii. Mr. Campbell assisted in the field work and wrote the beach descriptions for Kauai and Oahu. Mr. Stice assisted in the field work and was in charge of maintaining the equipment.

Valuable support was given, whenever requested, by Mr. D. C. Cox, then Executive Secretary, on behalf of the Institute of Geophysics, and by Dr. R. W. Hiatt, then Director of Research, on behalf of the University Administration. Mr. Cox also wrote the section on tsunamis, and was consulted frequently for his lifetime of observations on local geologic processes. Institute staff members who are thanked for their help are Mrs. D. A. Davis for accounting, Mrs. C. B. McAfee for editing, Mrs. I. C. Young for typing, Mr. R. Rhodes for illustrations, and sundry typists and draftsmen for their help.

I am also grateful for the assistance of graduate students L. D. Baver, Jr., and A. Kranek, and undergraduate T. C. Bryant, and several other graduates and undergraduates as well who helped in the field and in the laboratory. Dr. G. A. Macdonald, Senior Professor of Geology, was generous of his time in discussing a number of geologic problems. Dr. A. T. Abbott, Chairman of the Geology Department, Dr. A. H. Banner, then Director of the Marine Laboratory, and Mr. H. W. Butzine of the State Harbors Division all assisted materially by lending valuable equipment. Mr. S. Price of the U. S. Weather Bureau and Mr. R. Q. Palmer of the U. S. Army Corps of Engineers discussed certain aspects of their own special fields. Niihau was visited through the courtesy extended by Mr. Aylmer Robinson. Mr. W. Morris was very helpful in his liaison activities with the Planning Department.

This report has been read in whole or in part by Messrs. Chamberlain, Cox, McCoy, and Campbell, and I am grateful for their comments. The responsibility for any errors of fact or for misinterpretations must, however, remain with me.

GEOLOGY OF COASTAL SEGMENTS

General Statement

Certain extensive lengths of coast have in common such geologic features as geomorphology, bedrock types, geologic history, and beach systems, and thus can be treated more or less independent of other coasts.

This section of this report should be studied with the aid of the large planning maps drafted for the over-all shoreline study by the State Department of Planning and Economic Development. The delineation of shoreline characteristics of the six largest islands, as shown on these maps, was prepared by the Hawaii Institute of Geophysics from ground or nearshore boat observations, with aid from air photographs, charts, and maps. A few coastal segments were not observed at close range.

A primary distinction for the mapping was made between artificial and natural shorelines. Among the former are piers, jettys, groins, seawalls, fishpond walls, moles, drainage culverts, and road embankments. The natural shorelines are divided between those with rock exposed at the waterline and those with sediment at the waterline. The rock might be outcrops of lava bedrock, beachrock, raised coral reef, or old, lithified sand dunes.

The sediment category is further subdivided on the basis of grain-size into gravel, sand, and mud. Coarse material, from boulders through cobbles and pebbles, is termed gravel. Waterline accumulations of fine gravel, especially of somewhat flat pebbles, or shingle, are shingle beaches. At the other extreme a somewhat arbitrary distinction is made between the largest boulders and actual bedrock on some rocky coasts. Accumulations of sand-sized sediment in the coastal zone dominated by waves are sand beaches. Silt- and clay-sized sediment is called mud if wet (dust, if dry); it usually is wet in coastal zone accumulations called mudflats or, if within the tidal range, tidal mudflats.

Some combinations of the five symbols for artificial, bedrock, gravel, sand, and mud shorelines are necessary to depict such areas as those where bedrock is seasonally covered and uncovered by sand. Areas of poor sediment-sorting in some deltas or along reef-protected coasts may have a special note about sandy muds, muddy gravels, and so forth.

The personnel of the Institute of Geophysics also marked categories of ease of physical aaccessibility to the shoreline. This is a very subjective consideration and certainly is open to reevaluation depending on whether studied by an agile, 20-year-old local man or a stout, arthritic 70-year-old tourist woman. Shores that can be reached with ease by most persons are left unmarked. Shores that are difficult to reach by most persons are shown with one symbol, and shores that cannot be reached by most persons, with a different symbol. Access consideration is only physical, and is dependant on steepness of slopes, frequency of high waves, and length of trail from the nearest roads; it is not based on social considerations, such as access across military or private lands.

Kauai

Introduction. The nearshore geology of Kauai, outlined broadly here, is described in more detail in the following eight sections, one for each coastal sector having common physical features. Macdonald, Davis, and Cox (1960) have demonstrated that Kauai consists principally of a single huge shield volcano built of basaltic lavas, with a large collapsed crater area, or caldera, and south (Makaweli) and east (Lihue) collapsed flank areas. The caldera and southern depressions were filled with lavas related to the shield volcano, and all of these rocks are known as the Waimea Canyon volcanic series. After a long period of erosion, volcanism was renewed from several vents in the eastern two-thirds of the island, filling the eastern collapsed area and most of the remainder of the countryside. Only the highest ridges remained uncovered by this second group of lavas, the Koloa volcanic series. The youngest Koloa eruptions appear to be Late Pleistocene in age because they rest on lithified calcareous dunes, formed during one of the Pleistocene low stands of the sea, and, in turn, the lavas have marine deposits on them or have had terraces cut into them by stands of the sea 5 and 25 feet above, and 60 feet below, present sea level.

During the Pleistocene epoch erosion of sea cliffs and river valleys and the production of sand for dunes were controlled by the changing level of the sea. Valleys graded to a lower stand of the sea were alluviated and their mouths drowned to make bays when the sea level rose again.

Kauai has the longest stretches of good beaches in the Hawaiian Islands. Only in the Kapaa, Hanapepe, and Kekaha areas are the beaches being eroded seriously today. Kauai has high sea cliffs where Waimea Canyon volcanic series rocks are at the shore, and low sea cliffs where the shore is Koloa volcanic series rocks. Shallow fringing reefs are common on the north and east coasts, and less regular reefs are present elsewhere.

Lihue coast (part of K-1). The first two sections described are small. The section of coast from about one-half mile north of Hanamaulu Bay to Carter Point south of Nawiliwili Bay is mainly sea cliff 20 to 40 feet high. In cliff height and embayments it closely resembles the northeast coast of Kauai, from which it is separated by a length of narrow coastal lowlands.

The hinterland of the Lihue section is entirely lava, mostly of the Koloa volcanic series, and has low relief except where the few major streams have cut canyons 100 to 200 feet deep. The stream canyons were graded to a lower stand of the sea, and their lower ends were then drowned by the last rise of the sea. The middle sections of the valleys were therefore alluviated by the resultant diminished stream gradient.

The shoreline is low sea cliff except at the bays. A river-mouth barrier beach has formed at the head of Hanamaulu Bay, and formerly there was one at the mouth of Huleia Stream on the west side of Nawiliwili Bay. There is now a beach at the north end of that bay, and part of the shoreline in the bay is artificial from harbor facilities.

Offshore there are no shallow reef areas along this coast, except for small ones on either side of the entrance to Hanamaulu Bay. Both Hanamaulu Bay and Nawiliwili Bay have bottoms of fine sand and silt, which are among the finest-grained sediments known on Kauai.

Haupu coast (part of K-1). The coast from Carter Point, at the south edge of Nawiliwili Bay, to four miles southwestward past Kawelikoa is a small segment sufficiently distinctive from the adjoining coasts to warrant a separate description.

The hinterland is composed of lavas of the Waimea Canyon series, the older of the two major groups of volcanic rocks on Kauai. The younger group, the Koloa series, is the volcanic bedrock of the remainder of the coast from Hanalei Bay clockwise to Waimea. The east-trending ridge, of which Haupu is the highest point, is the southern rim of the Lihue Depression and was the site of an old, small caldera on the southeast flank of the main shield volcano. Kipu Kai, a crescentic valley floored with old and young alluvium, is near the southwest end of this coastal segment.

The shoreline is principally sea cliff, second on Kauai to the Napali Coast in height and ruggedness. Along Kipu Kai the shore has three sandy beaches as wide as 200 feet. The straight northern beach is separated from the crescentic middle beach by a ridge with a boulder beach at its seaward end. The middle beach, backed by active dunes 20 to 30 feet high, is separated from the southernmost beach by a pair of small rocky ridges of eolianite, the rock of lithified, ancient sand dunes. The southern beach is longest of the three, about 3500 feet long, and is backed by dunes 50 to 60 feet high. The eolianite ridges, as well as the recent unconsolidated dunes, are aligned parallel to the northeast trade winds.

A narrow but shallow reef fronts part of the northern beach, and some other irregular reef areas are present elsewhere, but in general there is water 60 or more feet deep within one-half mile of the Haupu area shoreline.

<u>Koloa coast (part of K-1, K-2; part of K-3)</u>. The hinterland of the coast from Haupu ridge west to Waimea River is volcanic rocks of the Koloa series, mainly lava flows with surfaces that dip gently southward. Hills that are spatter cones, marking vents of the Koloa series, and a few alluviated valleys interrupt the rolling landscape.

From Kawelikoa Point to Makahuena Point the shoreline is a series of points made up of eolianite between which are beaches backed by active dunes that extend as much as three-quarters of a mile inland. There are several beaches from Makahuena Point to Spouting Horn, but these beaches are both short and narrow and some of them are seasonal. Much of the coast is rocky from outcrops of Koloa lavas or beachrock. A terrace five feet above sea level provides easy access to the shore in calm weather. From Spouting Horn to Hanapepe Bay the shoreline is a rocky sea cliff of outcropping Koloa lavas; Makaokahai is a spatter cone, and Lawai, Wahiawa, and Hanapepe Bays are drowned river-valley mouths. The beach at Hanapepe is a river-mouth barrier beach that in times of flood is cut through by Hanapepe River. The beach becomes a boulder beach at its west end. West of Puolo there is beachrock at sea level. Some sand has been deposited behind it, and there is a crescentic beach where the beachrock ridge has been breeched. The rocky coast of Koloa lavas continues to Waimea, broken in several places by beaches that become larger and more common as one travels northwestward past Makaweli Landing.

The offshore area of the Koloa segment of coast has shallow areas between Kaumakani and Waimea and along the alignment of young vents, as the reef off Poipu and Kalanipuao Rock off Makaokahai, but most of the offshore area is moderately deep near shore.

Mana coast (K-3). The coast from Waimea to Polihale has the only extensive coastal plain on Kauai. It is also distinguished by long stretches of beach.

The hinterland of this coastline is an elevated former sea cliff of Waimea Canyon volcanic series basalt; it increases in height from less than 300 feet near Waimea to 1200 feet at Polihale. The cliff is dissected by the valleys of intermittent streams. The coastal plain between the foot of the cliff and the sea is more than two miles wide in the center, tapering away to the north and to the southeast. The plain was mapped and described by Macdonald, Davis, and Cox (1960) as a broad band of younger alluvium lapping onto a curved band of poorly sorted lagoonal deposits that are earthy inland and more calcareous seaward, and bounded by a narrow band of beach. The pattern of curved, low, sandy ridges paralleling one another, and also paralleling the present beach, indicates that the area between Nakeikei Elima and Waiokapua termed lagoonal deposits has at its surface raised beach ridges, so that Kokole Point is a cuspate foreland.

The shoreline is a narrow beach from Waimea River about nine miles past Oomano Point at Kekaha and Kokole Point to Waieli. At times the beach at Kekaha has been eroded back to beachrock, and rubble has been dumped as riprap to protect the highway foundation. There has been too little time since its construction to evaluate fully the effects on the beach of the artificial small-boat harbor between Waimea and Kekaha. The shoreline from Waieli to Nohili Point, about 3-1/2 miles along and fronting Bonham Airfield, is beachrock. At the south end the beachrock is exceptionally massive, and it has been broken along joints into blocks a few feet on a side. The four miles of coast from Nohili Point to Polihale is mainly a wide sandy beach. Near the southern end, the area called Barking Sands, a length of beachrock is uncovered most seasons. Behind this patch and the long stretch of beachrock south of Nohili there were brackish swampy areas, an interesting coincidence when speculating on the origin of beachrock. A long ridge of partly active dunes with blow-outs trending about N20°E is behind the beach. Dune elevations are highest at Nohili.

The shallow sea floor off the Mana coast is mainly fairly shallow. Sand, in a shallow, gently sloping apron off Waimea River, and in submarine bars farther west, covers most of the shallow bottom from Waimea to Waieli.

The ocean bottom off the beachrock coast is mixed coral reef and sand, whereas the bottom off the Nohili-to-Polihale beach is mainly sand. Farther offshore, this latter coast is one of the most interesting in Hawaii. Here the 300-foot bathymetric contour bulges to four miles offshore, exceptionally wide for these islands. A submarine ridge that is an old coral reef trends in a broad arc from Nohili northward, and then eastward to Makuaiki Point on the Napali Coast.

Napali Coast (K-4). The high cliffs cut by wave action, which extend from Waimea to Hanalei, are being actively cut by waves at the present day from Polihale nearly to Ka Lae o Kailio. Sea cliffs in this shoreline section, the Napali Coast, are among the highest and most scenic in the State.

The hinterland of this coast is basalt flows and dikes of the Waimea Canyon volcanic series, cut by stream erosion into deep valleys. The ends of the interstream ridges have been cut off by marine erosion into the spectacular cliffs. From Polihale to Milolii the faceted cliff-ends of the ridges are fairly straight and about 1250 feet high. Beyond the bend in coastal trend near Milolii the cliffs are higher, but are more irregular because of the broader valleys. At a few places the cliffs are 3000 feet in elevation within one mile of the shore. Most of the valley floors have thick deposits of older alluvium, and some of the deposits have been cut into terraces that stand well above sea level.

The Napali shoreline is mainly lava bedrock, but there are boulder beaches and small seasonal sand beaches at the foot of some cliffs and especially at the mouths of some streams. Small sand beaches at Honopu Valley and at the bay one-third mile east of there, and the south end of the long sand beach at Kalalau, are all reported to be present throughout the year.

The 60-foot bathymetric contour lies close to the Napali shoreline, but the offshore geologic feature of most interest is the system of submarine canyons that head close to shore, in the section of coast with the wide valleys, and extend several thousand feet down the island slopes. The possible significance of these canyons in the loss of shallow-water sediment to deep water is discussed in the section on sediment loss.

Haena-Hanalei coast (part of K-5). The windward Kauai coast is indented with small bays that are drowned river valleys, and there are lengthy sections of shallow fringing reef offshore. From the end of the Napali Coast near Ka Lae o Kailio eastward past Haena to the east end of Hanalei Bay there is a narrow coastal lowland.

The hinterland of this coastal segment is one of the most complex areas of geology, both in topography and in bedrock-type, in all Hawaii. Most of the area is underlain by lavas of the Waimea Canyon volcanic series, both the thin flank flows that built the shield and, two or three miles inland from the shore, the later and thicker flows that filled the collapsed caldera. The heads of the large perennial streams extend back into the caldera region. The eastern tributaries of Hanalei River chiefly drain a large area of the young lavas of the Koloa volcanic series, and there are several small areas of Koloa lavas in the valleys of the Wainiha and Lumahai Rivers. There is considerable older alluvium in the middle stretches of the river valleys, and near their mouths there is younger alluvium which spreads over a narrow coastal plain along with beach deposits. Old sea cliffs, some with former sea caves, are now at the inner edge of the plain.

The shoreline is embayed slightly at Manca Stream west of Haena and moderately at Wainiha Bay into which both the Wainiha and Lumahai Rivers formerly flowed before Lumahai River was diverted slightly to the east by the late valley-filling Koloa series lava flow that now makes Kolokolo Point. Hanalei Bay is the largest bay, not only of this coastal segment, but also of the entire island. The large Hanalei River and the smaller Waipa and Waioli Rivers enter it. The shoreline of this coastal segment is mainly beach, interrupted only by some rocky headlands of Koloa lavas eroding into sea cliffs. All these beaches except Hanalei suffer great changes periodically, and even the Hanalei beach has a considerable annual fluctuation in width. Erosion by winter northern swell exposes patches of beachrock locally from the western edge of beach east to Wainiha Bay. The river-mouth barrier beach at Wainiha changes whenever Wainiha River changes its course in time of flood. In fact, this is also true of the west end of Hanalei Beach near the mouths of Waipa and Waioli Rivers, and meander scars which are apparent in air photographs show that even Hanalei River has meandered in the recent past. The photographs of old beach ridges also indicate that the entire crescent of Hanalei Beach has been slowly aggrading northward into Hanalei Bay in recent times.

The offshore area is partly reef and partly sandy bottom. The reefs appear to be among the most vigorously growing reefs in Hawaii, and are very shallow with strong currents that sweep over them. The reef front at Haena Point curves 1500 feet offshore, but most of the reef flats are fringes less than 600 feet wide. An irregular bottom continues down to 50 or 60 feet. Some of the sandy areas have scattered coral heads growing on them, and the areas generally become rockier downslope. Most of the sand-bottomed areas are off the river mouths.

Northeast coast (part of K-5; part of K-6). From Hanalei to Kealia much of the coast is low sea cliff fringed by shallow reefs, with a few bays that are drowned river-valley mouths. Except for these valleys there are but few coastal lowlands.

Inland from the shore most of the bedrock is Koloa volcanic series lava flows, erupted after a long period of erosion of the earlier Waimea Canyon volcanic series lavas, and burying all except the highest ridges such as Kekoiki and Puu Ehu. There are several Koloa series vents in this hinterland, and one near Kilauea is the only tuff cone on Kauai. Older, partly consolidated alluvium is plastered against the lower slopes of the higher ridges, and the lower reaches of the drowned valleys are being alluviated under present geologic conditions. This northeast area of Kauai is very deeply weathered. Some of the bauxite deposits of Hawaii, which may prove to be economically valuable, were formed by the deep weathering.

Along the shore eastward from Hanalei River to Kilauea there is a sea cliff that is 100 to 200 feet high. West of Anini Stream there are some small beaches in front of the cliff, but at Anini Stream and eastward the beaches are longer and wider. Kalihiwai Bay, a drowned river valley in the middle of this last-named section of coast, has a river-mouth barrier beach. East of the sea cliffs at Lae o Kilauea are the marine-eroded remains of a tuff cone formed by violent steam explosions when rising Koloa series lavas encountered sea water. Kilauea Bay also is a drowned valley with a river-mouth barrier beach. The shore southeastward to Kealia is about half beach and half sea cliffs rising 20 to 200 feet high. The cliffs are highest near Kilauea and Moloaa Streams. Moloaa and Anahola Bays are additional drowned river valleys with barrier beaches, whereas the other beaches in this section are mainly behind fringing reefs.

About two-thirds of the northeast coast is fringed offshore by shallow reefs. The reef flats west of Kalihiwai are as much as 1600 feet wide, but they are less than half this width along the coast to the southeast. Farther offshore, a very broad submarine ridge extends northeastward from Kauai into deep water.

Eastern low coast (part of K-6; part of K-1). From the north end of Kealia to the sea cliff that starts one-half mile north of Hanamaulu Bay the coast is generally low and accessible. Rivers empty into gentle scallops of the coast rather than into deeper bays.

The hinterland of this coast is much like that described for the northeast section, Koloa lavas lapping against old hills of Waimea Canyon lavas. Nonou and Kalepa Ridge, paralleling the coast a mile or two inland, are unburied remnants of the older volcanic series which form the eastern rim of the Lihue Depression, a collapsed segment of the east flank of the main volcano that was filled with Koloa series flows from Kilohana Crater and other vents. Lowlands of alluvium and shoreline deposits extend as much as a mile inland of the shore along most of the coast. Between Kealia Beach and Kapaa Beach the shoreline is low sea cliff of Koloa lavas, and there are a few lava outcrops at each end of Wailua Beach, but the rest of the shore is beach or beachrock. The beaches are moderately wide at Kealia and Wailua, where they become river-mouth barrier beaches. Along a significant part of the Kapaa sector between these locations, however, the seacoast is eroding rapidly and its beaches are only a few feet wide in many places. Beachrock and low sea cliffs a few feet high cut into old alluvium, and beach sediments are of common occurrence, especially inland from the part of the reef recently dredged. The beach extending nearly three miles south of Wailua is narrow at its ends, but wide in its middle portion where dunes have been formed behind the beach.

Off Kealia and its adjacent cliff to the south the bottom slopes moderately, and is partly sand and partly rocky from patches of coral. From Kapaa southward there is a distinct fringing reef along most of the coast. Off Kapaa it is very shallow and widens to 1200 feet from shore to reef edge. The broad sand-bottomed channelhead, located offshore between the two drainage canals emptying between jettys, interrupts the reef, which then continues to Wailua Beach and another broad sand-bottomed channel. South of Wailua River the reef edge is close to shore and the reef surface is more irregular and with larger patches of sand than to the north.

Oahu

Introduction. The geology of Oahu has been described by Stearns and Vaksvik (1935). Essentially, Oahu consists of two major shield volcanoes, the eroded remnants of which are the Waianae Range and the Koolau Range. Eruptions of the Koolau volcanic series continued after Waianae activity had ceased. The large caldera area for Koolau volcano is in the Kailua-Kaneohe Bay area, and the caldera area for Waianae volcano is around Kolekole Pass. The major rift zones trend toward present-day Kahuku, Makapuu, and Barber's and Kaena Points.

During the Pleistocene three main geologic events were occurring on Oahu. The deep stream erosion of the two shields continued. A group of secondary eruptions, known as the Honolulu volcanic series, added such well known features as Diamond Head and Koko Head to southeastern Oahu. Coral reefs and marine terraces were formed at different elevations due to the changing sea levels in the Pleistocene. These erosional features, volcanic eruptions, and ancient shorelines have had a complicated and interrelated history which Stearns (1935) began to decipher, and in which several other geologists have been interested.

Oahu has more coastal plain and reefs but fewer sea cliffs than any of the other Hawaiian islands. Its beaches are second only to Kauai's in extent, and are first in the State in use by residents and visitors. Its coastal areas also have the most important city, suburbs, harbors, airport, and industrial development in Hawaii, and a major share of the facilities for armed forces and tourists. Eleven subdivisions of the Oahu coastline are described below.

Maunalua Bay (part of O-1). The south-facing coast of Oahu from Koko Head westward to Kahe Point has several features that tend to set it apart from adjacent coasts. The coast is generally low, mainly on an old coral reef now elevated 25 to 50 feet above sea level, and there is easy access to all parts of the shoreline. The southern exposure and the fringing reef make this coast one of the most protected from all types of waves, including tsunami. This coast is the most important economically in the State, with the greatest urban development, the two finest existing harbors, and a large share of the armed forces establishment. It has an eastern section bordering Maunalua Bay, a central section that is urban Honolulu, and the Ewa Plain at the west.

The hinterland of the eastern part of this coast is chiefly the moderately dissected south slope of the eastern end of the old Koolau volcano, now the Koolau Range. The valleys generally are short and narrow, widening somewhat at their lower ends, and containing only intermittent streams.

Two lines of vents of fairly recent volcanic activity and respectively at Koko Head and at Diamond Head, projecting south from the general coastal alignment and forming the ends of Maunalua Bay. Most of the land suitable for man's use is in the angles between the headlands and the general coastal alignment at Kahala and at Kuapa Pond, or in the lower ends of some valleys.

The shoreline of Maunalua Bay is largely artificial at the present time. At Kuapa Pond the Hawaii-Kai real estate developments change the shoreline configuration from time to time. The shoreline is mainly seawall, from Paiko Peninsula, a sand and gravel spit protecting a mudflat, westward to Black Point, a rocky headland formed when lava from a late eruption flowed seaward across the reef. At Niu and Wailupe the walls bordered old fish-ponds, now filled for residential areas. Most of the low seawalls have narrow, poorly sorted gravel to sandy beaches that front them. The Kahala-Hilton Hotel interests hope that artificial islands offshore from their hotel will protect the beach they intend to establish there along the shore. Stretches of rocky coast on which is cut a terrace about 5 feet above sea level alternate with narrow beaches in front of Diamond Head.

The offshore area of Maunalua Bay is characterized by one of Hawaii's shallowest reefs. Relatively few organisms appear to be living on this reef-flat. Local patches of sand are on the reef as well as in a few sand-filled channels that traverse it. The largest offshore sandy area extends downslope southwest from the Kuapa Pond-end of the bay.

Urban Honolulu (O-2). Between Diamond Head and Salt Lake the Koolau Range is separated from the shoreline by a low coast one to two miles wide. The wide, amphitheater-headed valleys of this part of the Koolau Range, Palolo, Manoa, Nuuanu, and Kalihi, are floored with alluvium or late volcanic materials that grade seaward into elevated coral reefs. Much of the seaward-most part of the coast is artificial, an area of former mudflats, fish- and duckponds, and reef that has been filled from adjacent dredging. These lowlands, and some of the lower ends of Koolau Ridge, are the urban areas of Honolulu proper with a great concentration of residences, offices, factories, wharves, airports, and schools. One of the most valuable natural resources of Hawaii, Honolulu's artesian groundwater system, lies under this area.

The Waikiki shoreline at the east end of this segment of coast is now mainly artificial. Waikiki Beach was formerly a barrier beach in front of the Ala Wai swamps, now drained and filled. The beach has several groins and seawalls, and has periodically been nourished by sand artificially transported from Keawaula (Yokohama) Beach and from Bellows Field. From the west end of Waikiki to the entrance of Pearl Harbor all of the shoreline has been altered, chiefly in this century. Additional re-shaping is underway now or planned for the Ala Moana, Honolulu Harbor, and Keehi Lagoon portions.

Offshore, the reef-flat varies in width from none, where filled land has completely crossed the shallow water, to two miles at Keehi Lagoon. The reef has been extensively dredged for navigation at Ala Wai, Kewalo, and two entrances to Honolulu Harbor, for seaplane runways at Keehi Lagoon, and for fill off Ala Moana and Fort Kamehameha. Moderate dredging of coral heads to improve swimming and surfing off Waikiki may have accelerated beach erosion there.

Ewa Plain (O-3; part of O-4). The broad Ewa Plain is the hinterland for the western end of Oahu's south coast. The northeastern edge of the

Plain is the low area across which nearly horizontal late flows of the Koolau volcano banked against the dormant or newly-extinct Waianae volcano. The main feature of this area is Pearl Harbor, a drowned river valley, now a naval reservation. Aiea, Pearl City, and Waipahu are towns bordering Pearl Harbor. Of shoreline geologic interest are the near-sea level Pearl Harbor Springs from which several hundred million gallons of fresh water are lost yearly into Pearl Harbor.

The south part of Ewa Plain itself is an old coral reef, formed at a higher stand of sea level and now exposed. Northward the reef limestones interfinger with sands, muds, and gravels that were the ancient lagoonal deposits behind the reef, and with alluvium washed down from the south end of Waianae Range. Most of the Ewa Plain is in irrigated sugar cane or is wasteland because of the low rainfall. A naval air station and smaller federal establishments and growing residential and industrial areas characterize the plain. Geologically, Hawaii's greatest onshore limestone resources are there.

The shoreline west from Pearl Harbor entrance to Nimitz Beach is a coast of alternating stretches of rocky and sandy shoreline. Some rocky areas are outcrops of the raised reef limestone, and some are of beachrock. West of Nimitz Beach, artificially constructed, to Barber's Point and thence north to Kahe Point, the shoreline is rocky except for a small beach a mile south of Kahe Point. Along part of the coast, however, there is sand immediately inland of the water-level beachrock. A small barge harbor now exists two miles northwest of Barber's Point, and it is planned to enlarge it to a deep-water harbor for large ships.

A fairly wide reef, not as shallow as those fringing Maunalua Bay, discussed above, is present from Pearl Harbor entrance west to Barber's Point. A sand-floored channel crosses the reef at Oneula Beach; the offshore area west of that channel was not observed closely. Northwest of Barber's Point the reef is very narrow.

Western coast (part of O-4; O-5). Western Oahu, from Kahe Point to Kaena Point, is characterized by a hinterland of broad, arid valleys alternating with steep-sided ridges, by a shoreline of rocky stretches and stretches of excellent beaches, and by an offshore area of very narrow reefs and of a steeper descent to waters of a few hundred fathoms than is characteristic of any other coast on Oahu. Differences in features from one end to the other are not great enough for further subdivision of this coast.

The western slope of the old Waianae volcano, now the Waianae Range, is cut into several large valleys. The coast has three broad bights, between Kahe and Maili Points, between Maili and Kepuhi Points, and between Kepuhi and Kaena Points. The widest and longest valleys, Lualualei, Waianae, and Makaha, open into the middle bight. Nanakuli Valley to the south and Makua Valley to the north are the other areas of low, fairly level land, and there is no coastal plain along the west coast. Most of the hinterland is in naval or military reservations, or in homestead lands, or is unimproved.

The rocky parts of the shoreline are outcrops of Waianae basalt bedrock or raised coral reefs at Kahe Point, Kalanianaole Park and Nanakuli, Maili Point, Puu Mailiilii, Kaneilio Point, the shore north of Pokai Bay, Mauna Lahilahi, Makaha, Kepuhi Point, Heeau Park, Barking Sands, the unnamed ridge north of Makua Valley, and the final 2-1/2 miles to Kaena

Point. Most of the raised reef makes a terrace 5 to 10 feet above sea level. The remaining rocky parts of the shoreline, as at Lualualei Homesteads near Nanakuli, parts of Maili Beach, the straight coast south of Kaneilio Point, and some other patches, are beachrock.

There are beaches north of the new power plant at Kahe, at Nanakuli, between beachrock outcrops at Maili, at Pokai Bay and locally to the northwest, at the south and north outskirts of Makaha, locally along the Keaau coast, at Makua, and at Keawaula (Yokohama). Of these, Maili, Pokai, Makaha, Makua, Keawaula, and Nanakuli under certain wave conditions are the largest and most popular. Except for Pokai, protected by a breakwater, these beaches have steep foreshores, pronounced seasonal changes, and dune ridges.

The reef area offshore is very narrow and has but few living corals. Sand-bottomed channels are present off most of the beach areas. They and the adjacent reef slopes descend to deep water rapidly.

North-facing coast (part of O-6). The main coastal features of the coast from Kaena Point to Kahuku are the strong winter surf and the irregular reef. The coast can be subdivided into four segments from differences in coastal plain, occurrence of beaches, and reef characteristics.

The hinterland of the coast from Kaena Point to north of Waialua is the northwestern ridge of the Waianae Range and a coastal plain on terraces about 25 feet above sea level that widen eastward from Camp Erdman.

The shoreline west of Camp Kaena is a platform cut into lava bedrock near present sea level. Generally, this is covered with boulders and cobbles, but there are stretches of bare beach and a few tiny pocket beaches. East of Camp Kaena is a 6-mile length predominantly of sand, Mokuleia Beach. About one-sixth of the coast is beachrock, exposed year round, and more uncovers in the winter and early spring. Usually there is sand behind the beachrock. There are extensive dune ridges along this coast, some of which have been dug into for sand for construction purposes. Most dunes are stable, but some at the west end are active. Near Kaena Point sand is blown inland.

The offshore topography varies greatly in both width of reef and irregularity of its surface. Old beachrock ridges awash at low tide and small channels crossing the reef add to the irregularity. A large channel crosses the reef diagonally northwestward.

Haleiwa coast (part of 0-6). The hinterland around Haleiwa is a gentle coastal plain sloping inland to the saddle between the Koolau and Waianae Ranges. The area has sugar plantations and small towns.

From the unnamed broad point one mile west of Kaiaka Bay northeastward to Puaena Point, the shoreline has two bays and present or former beaches. Puuiki Beach and the military beach are good at the present time, but Haleiwa Beach on the east shore of Wailua Bay has been eroded back to the beach-park seawall. A major project under consideration is to rebuild that beach concurrently with improving the Waialua Bay-Anahulu River small-boat anchorage.

The main feature of the offshore topography is the pair of submarine canyons, or large channels, that head in the bays. One trends along the shore from Kaiaka Bay, then turns abruptly north across the reef. The other is branched, one fork leading out from Waialua Bay and the other from the shore about midway between the two bays. The reef is rather wide off this segment of Oahu.

Northwest-facing coast (part of 0-7). From Puaena Point to Waialee the hinterland is a very narrow coastal plain 10 to 30 feet above sea level. Next inland is a cliff a few hundred feet high, probably cut as an old sea cliff against the northwest flank of the Koolau Range during the higher sea level when the coastal plain was formed. The Koolau uplands here slope gently seaward to the cliff edge and are cut by youthful streams a mile or so apart.

The shoreline at Puaena Point is a low cliff that cuts a terrace of old reef limestone. Eastward, the rocky shore becomes beachrock. Along Kawailoa Beach there are stretches of beachrock and of sandy beach; some of the beach is seasonal. There are wide expanses of rocky coast, mainly lava bedrock, to either side of Waimea Bay. The most important of the few river-mouth barrier beaches on Oahu is the one at the head of the bay. Sunset Beach, extending northeast for two miles beyond the Waimea rocky coast, is predominantly a wide sandy beach, but there are some patches of beachrock. Northeast of Sunset Beach are two small, broad rocky points flanked by beach.

Off Kawailoa Beach the reef is irregular with sand patches and a few small channels. The offshore topography is steep past Waimea Bay and the shores are rocky to either side of the bay. Off Sunset Beach there is, again, a wider, irregular reef with abundant patches of offshore sand. Northeast of Sunset Beach there are large patches of reef and beachrock awash at low tide.

Kahuku coast (part of 0-7). From Waialee past Kahuku Point to Makahoa Point there is a broader coastal plain characterized by hills of old, lithified sand dunes and marshy lowlands. The northern end of the Koolau range rises with moderate relief behind the plain of sugar cane fields.

The shoreline is mainly rocky. In general, points of land of this irregular coast are of raised reef limestone and in between are extensive developments of beachrock. There is considerable sand near the shore, but, except for beaches at Kawela Bay and fronting the town of Kahuku, most of the sand is in storm beaches immediately inland of the beachrock or in the active and stabilized dunes. Drifting sand covers large areas of the old airstrips.

As is so common on the north coast of Oahu, the reef off this section is very irregular, with patches of sand and small channels, and with many rocks awash at low tide. The reef is slightly narrower in the middle of this section, off Kahuku Point.

<u>Laie-Kaaawa coast (most of O-8; part of O-9)</u>. The eastern or windward coast of Oahu, with its relatively wide reefs and tradewind-generated waves, can be divided into three large and two small segments having common geologic characteristics. The northwest end is herein called the Laie-Kaaawa coast.

The hinterland of the coast from Makahoa Point to Kuloa Point is a narrow coastal plain backed by the east flank of the north end of the Koolau Range. Relief increases to the south, and Punaluu, Kahana, and Kaaawa Valleys there have flood plains near their mouths.

Much of the shoreline is beach, but the beaches are all very narrow with the exception of that at Laie Bay. Laie Bay and the unnamed bay north of it are formed by projecting points and adjacent islands of old, lithified sand dunes and raised reefs. Part of the coast at Punaluu and at Kahana Bay is rocky, made up of boulders and cobbles. Seawalls are common along parts of the shoreline.

The most impressive aspect of this coast from the geological standpoint is the broad, shallow, and generally smooth reef-flat, with a sparse amount of sand on it, trenched by sand-bottomed channels 1000 or more feet wide with heads close to shore usually off valleys of the hinterland. From north to south there is a channel in Laie Bay that is fairly gentle, but the channels at North Hauula, Hauula (forked), Kaulanui, Punaluu (with one tributary), Kahana, and Kaaawa have steep sides 20 to 40 feet high. There are a few smaller ones as well.

Kaneohe Bay (part of O-9). Inland from Kaneohe Bay there is the most deeply dissected part of the Koolau Range, in the area of the old caldera. There are some moderately broad lowland areas in the lower reaches of deeply alluviated valleys.

Because Kaneohe Bay has a deep lagoon between an outer reef and the shore, the reef is considered by some geologists to be a barrier reef, the only example in Hawaii. Because of low wave energies in the bay, precluding much reworking along the shore, most of the streams entering the bay have built small deltas. The poorly sorted sediments of the shoreline are sandy, gravelly muds. Mangrove is beginning to grow at several localities and is well established at Heeia. Several fishponds, commonly being filled now for residential development, line the bay. Mokolii (Chinaman's Hat) and Mokuoloe (Coconut Island) are erosional remnants of the bedrock Koolau basalt, Kapapa and Kekepa Islands are of limestone, and Ahu o Laka Island is a sand bar that is uncovered at low tide.

Offshore, but within the bay, are extensive, shallow sand flats of irregular outline with sharp breaks in slope of coral reef down to 30 to 50 feet depth of water. The lagoon bottom is mud. The main channel that enters from the north end and much of the south end of the bay have both been dredged. The barrier reef is broad and sand-covered over most of its surface. It slopes eastward into the open ocean at about the same gradient as the Laie-to-Kaaawa reef to the north.

Mokapu Peninsula (part of 0-9). The minor coastal segment of Mokapu Peninsula, with its Marine Corps installation, separates Kaneohe Bay from Kailua Bay. Mokapu's existence is due mainly to a group of secondary volcanic eruptions that formed Ulupau Crater, Puu Hawaiiloa, Pyramid Rock, and the nearby Moku Manu (Bird Islands). Bedrock of these volcanic features forms the shoreline in some localities. The shore along most of the Kaneohe Bay-side is artificial, from fishponds, seaplane ramps, and dredging. Two beaches on the north coast are available for Marine Corps landing exercises. The offshore area was not observed close at hand, but charts show a steep slope.

Kailua-Waimanalo coast (most of 0-10). The hinterland behind the coast from Kapoho Point to Kaupo Beach Park is an area of broad lowlands, often swampy, and hills, mountains, and palis of Koolau flows and caldera fillings. Mokulua Islands off Lanikai are also of dikes and caldera-filling volcanic rocks, left isolated as erosional remnants.

The shore is two broad bays, Kailua Bay and Waimanalo Bay, separated by a broadly convex headland, Lanikai between Alala and Wailea Points. Each of the points, Kapoho, Alala, and Wailea, as well as the coast near Kaupo, is rocky, but the shores between are fair to excellent beaches. Dune ridges border most of Kailua and Waimanalo Beaches.

Shallow reefs spread offshore in a broad arc centered on Lanikai, and there are also shallow reefs at the north and south ends of this section of coast. The reef is wide but deeper off the middle of Kailua Bay and especially so off Waimanalo Bay. There are extensive areas of sandy bottom and some broad but not steep-sided sand channels on the reefs.

Southeast coast (part of O-10; part of O-1). A small segment of shoreline shaped mainly by secondary volcanic eruptions extends from Kaupo Beach Park to Koko Head. Part of the hinterland is the southeastern end of the Koolau Range, ending at Makapuu Head, but most of it is lava and consolidated volcanic ash deposits (tuff) from a line of secondary eruptions extending from Manana (Rabbit) Island to Koko Head. Where these are at the waterline the shore is rocky, as from the flow forming the broad peninsula between Kaupo and Makapuu Parks, at Kaloko, Halona (Blow Hole), and elsewhere. Commonly there is a distinct bench or low terrace cut in the tuff but not in lava, a few feet above sea level. Between rocky projections are small beaches: Kaupo, Makapuu, Wawamalu, and Sandy, and within two overlapping craters breached by the sea, constituting Hanauma Bay. Dredging near Kaloko presumably is in conjunction with the Hawaii-Kai project.

Offshore, as at Mokapu Peninsula along another line of vents, the water deepens rapidly. Individual marine organisms are common, but, except in Hanauma Bay, no reefs have developed. A sand-bottomed channel extends eastward from Makapuu Beach, and the offshore area between Makapuu and Halona has several sand patches.

Molokai

Introduction. Molokai was built of two large shield volcanoes, West Molokai and East Molokai. Stearns and Macdonald (1947) described the geology of this island. West Molokai consists of basaltic lavas erupted along rift zones trending northwestward and southwestward from the vicinity of Mauna Loa, and its igneous bedrock is known as the West Molokai volcanic series.

The higher eastern two-thirds of Molokai was also a basaltic shield volcano, but it has at its top a capping of thicker, more siliceous lava flows. All these rocks are the East Molokai volcanic series. West Molokai became extinct before East Molokai did, and thus its eastern flank is partly buried below late flows of East Molokai.

The Pleistocene history of Molokai was chiefly one of erosion. Severe stream and marine erosion on East Molokai exposed its caldera complex. Evidence of various changes of sea level are present on Molokai. Only two young secondary eruptions are known, a moderately large basalt lava cone that built Kalaupapa Peninsula, and the small tuff cone of Mokuhooniki off the east coast. Some lithified calcareous dunes and their unconsolidated modern equivalents are found on the northwest coasts, and the south coast has a long and narrow band of alluvial and marine deposits.

For the purposes of this report the coast of Molokai is divided into eight units having closely related features.

Mangrove coast (part of Mo-1; part of Mo-2). From Kaunakakai westward nearly to Kolo the coastline is distinctive because of its large areas of mangrove vegetation. The eastern part of its hinterland is the low, nearly flat southwest flank of East Molokai which is banked against the steeper eastern flank of West Molokai that is the western hinterland. A coastal plain has spread nearly a mile across the reef in the middle part of this coast in historic time, due to accelerated weathering after the introduction of agriculture and livestock.

Shoreline features are a delta at the mouth of Kaunakakai Gulch, a narrow beach in front of Kamehameha Grove, and a five-mile stretch of mangrove on tidal mud-flats. West of Pakanaka fishpond the shoreline generally has narrow, poor beaches. Some at the eastern end are mainly sandy, and some are chiefly cobbles, especially those at stream mouths. Small lengths of mixed cobble and sand beaches, old fishpond walls, and mangrove make up the remainder of the shoreline.

A reef fringes the coast with its edge about one mile offshore. It is being covered rapidly by red sediment washed down from the cultivated and grazed fields.

West coast (part of Mo-2; part of Mo-3). All of the hinterland from Kolo around Laau Point to Ilio Point is basalt of the West Molokai series, now moderately dissected by erosion of its intermittent streams.

The shoreline is partly beach and partly low sea cliff. Between the former wharf at Kolo and the new artificial harbor at Hale o Lono the shore is a mixed cobble and sand beach. It is sandier at either end than in the middle. The beach west of Hale o Lono is broken into four main segments by projections of basalt. Beachrock that underlies the sand is exposed seasonally as part of the sand is eroded. Sand movement along this southwest coast is very active. Basalt sea cliffs and lengthy exposures of beachrock are at the shore rounding Laau Point and as far north as Kaheu Gulch. Large areas of sand just inland from the shoreline result from deposition there by storm waves, and the features are called storm beaches. Kamakaipo has the largest storm beaches, which grade inland to dunes. Five sandy pocket beaches in tiny coves, like Kaunalu Bay, interrupt the low sea cliff with additional storm beaches and dunes that extend to Puu Koai. Next northward is Papohaku Beach.

Papohaku is one of the finest beaches in the Islands. It is two miles long and fairly straight, held between a lava headland at the south and a cinder cone headland to the north. North of the cinder cone is Kepuhi Beach, and there are some additional sand and gravel beaches between lengths of sea cliff out to Ilio Point.

Penguin Bank is a drowned coral reef at depths of about 175 to 200 feet extending southwestward from Laau Point. It may be an extension of the southwest rift zone of West Molokai, or it may represent a separate eruptive center. The fringing reef continues west of Kolo, but tapers away before reaching Laau Point. Off the west coast there are large patches of sand, especially off Papohaku Beach, and patches of coral and beachrock.

Northwest coast (part of Mo-3). The hinterland of the coast from Ilio Point to Moomomi is mainly lavas of the northwest rift zone of West Molokai volcano, but dikes and cinder cones are fairly common as well. Ilio Peninsula and most of the coast in the Kalani and Moomomi area are largely covered by eolianite, consolidated sand blown inland by the trade winds from beaches and off of reefs during former periods of lower sea level. Recent unconsolidated dunes extend 4-1/2 miles inland southwest of Kalani as the feature known as the Desert Strip.

The shoreline is a sea cliff ranging in height between 100 and 500 feet extending eastward from Ilio to Kapalauoa. East of Kapalauoa there are three calcareous beaches that are the sources of the recent dunes of the Desert Strip. Kalani Beach normally has eolianite at the waterline, then a 100-foot-wide storm beach. Kawaaloa is a moderate-sized pocket beach, and Moomomi is a tiny one at the east end of Moomomi Bay. This is one of the most impressive coasts of dune development in Hawaii.

Sea stacks, former parts of old sea cliffs isolated by marine erosion, are common off the higher sea cliffs of this coast. The bottom was observed from a small boat only in the vicinity of Moomomi, where there are large patches of sandy bottom, and off Kawaaloa beach where there is a coral reef.

North-central pali coast (small part of Mo-3; part of Mo-4). East of Moomomi Beach the coast is all sea cliff as far as Kalaupapa Peninsula. The hinterland is mainly the lower (basaltic) member of the East Molokai volcanic series, but these lavas have some small areas of eolianite on them at the west end of this coast, and a very extensive cover as much as a few hundred feet thick of upper-member lavas to the east.

The sea cliff increases in height from less than 50 feet near Moomomi to 1700 feet at the edge of the Kalaupapa Peninsula. The small indentation of Kapale Gulch is the only valley cutting the pali. From that point eastward there is a talus of boulders and cobbles at the waterline.

This coast was traversed by ship and by small boat, but there is deep water close to shore and no direct observations were possible. The north Molokai submarine slope has an impressive submarine canyon system off Kapale Gulch and to the eastward.

Kalaupapa Peninsula (part of Mo-4). Kalaupapa Peninsula is a small basalt cone built at the foot of the pali. The eruptions are the most recent on the island of Molokai.

At the southwest edge of the peninsula there is a modest-sized beach, and there are two smaller ones between Kalaupapa town and the airstrip near the tip of the peninsula. Storm beaches and patches of blown sand are common on the northern and eastern coasts. Aside from the beaches, the shore is sea cliff that is a few feet high on the west side of the peninsula and rises to about 100 feet at the southeast corner.

There is moderately deep water off all coasts except the northwestern one with its small fringing reef.

Northeast pali (part of Mo-4; Mo-5). Perhaps the most spectacular coast in Hawaii is the high sea cliff between Kalaupapa Peninsula and Cape Halawa. The central part of the cliff is more than 3000 feet high, and the rim is only 2000 feet inland, so that this is among the highest and steepest of the sea cliffs in the world. The complex group of rocks in the caldera of the East Molokai volcano, as well as more typical flows and dikes, make up the hinterland of this coast. The large valleys that scallop the cliff, Waileia, Waikolu, Pelekunu, Wailau, Papalaua, and Halawa, have alluviated bottoms.

The sea cliff is interrupted by valley mouths, some of which have beaches. Pelekunu and Wailau have a cobble-beach base with sand in summer months, and Halawa has two beaches, one of sand with dunes behind it, and one which seasonally covers the cobbles and boulders. There are five large areas of landslide deposits at the foot of the cliff. As the waves wash the finer fragments from them, they become steep boulder beaches.

There are several stacks offshore, including Mokapa and Okala, each more than 350 feet high. The entire coast was traversed by ship and small boat, but the only detailed bottom observations were made in Halawa Bay. Submarine ridges of boulders lie offshore there.

Mokuhooniki coast (part of Mo-6). A short stretch of coast southwest from Cape Halawa to Kanaha has low sea cliffs and no reef offshore. The hinterland is volcanic rocks of the East Molokai series, thin basalts capped by thicker, more siliceous flows, all dipping southeast from the volcanic center.

The shoreline is a sea cliff 100 feet high at Cape Halawa, but generally less than 50 feet high to the southwest. Only one of the gentle indentations of the coast has a pocket beach. Mokuhooniki and Kanaha Islands are the remnants of a tuff cone which erupted in the Pailolo Channel.

Fishpond coast (part of Mo-6; part of Mo-1). Most of the 53 fishponds on the south coast of Molokai are on the reef-flat between Kanaha and Kaunakakai.

The south-dipping slopes of East Molokai Mountain are mainly flows of thick siliceous lavas capping thinner underlying basalts. A narrow coastal plain has been built by the deltas of the intermittent streams that drain in a radial pattern the broadly convex south slope of East Molokai.

The shoreline is mainly artificial, the fishpond walls having been constructed by the ancient Hawaiians. Most of the walls are in ruins today and the ponds are silting rapidly. There are considerable lengths of sand beach, but in most places the beach is only a narrow strip a few feet wide. Pebble beaches are most common at the small deltas that mark the stream mouths.

A shallow fringing reef that commonly is more than a mile wide extends along all of this coast. There are natural deep indentations every mile or so along the eastern part of the reef. Considerable red silt is being deposited on the surface of the reef, but large patches of sandy bottom are also present.

Lanai

Introduction. Lanai was formed by a single basalt shield volcano. It has no capping of more siliceous lavas nor any secondary eruptions. Palawai Basin and the flat lands surrounding it indicate the caldera area, and the extension of flat lands to the northwest is due to the partial filling of the collapsed northwest rift zone. The windward, or northeast, flank of the old volcano has been eroded by streams to a local relief of several hundred feet. Wentworth (1925) and Stearns (1940a) have reported on the geology of Lanai.

Southwest coasts (L-1). Only one major division of Lanai's coasts is of significance, and that is the separation of the south and west coasts, which have sea cliffs in most places, from the north and east coasts, which have mainly a narrow coastal lowland and a fringing reef. The hinterland of the southwest coasts is the slightly dissected southwest flank of basaltic bedrock of the Lanai volcano.

The sea cliff that extends southwest from a point near Kapoho Gulch is low for the first mile, then is generally higher as far as the mouth of Manele Bay. Kalaeokahano is a vertical cliff of 350 feet. There is a small beach at the head of Manele Bay with sand and some beachrock. Stearns (1940a) reported a beachrock-like conglomerate from cemented talus along this part of the coast.

Manele Cone is a cinder and spatter cone that has been strongly shaped by marine agencies. Its east side is a sea cliff, Leinohaunui Pali, and offshore to the south lie Puupehe and other stacks. A bench about 5 feet above sea level borders the western side of the cone. The cone is now a peninsula, tied to the main part of Lanai by beach sediments that even today are still being deposited in Manele Bay and in Hulopoe Bay. West of the crescentic beach at Hulopoe Bay there is generally low sea cliff to Palaoa Point.

Pali Kaholo, which rises in height north from Palaoa Point to 1000 feet, and then dies away before reaching Kaumalapau Harbor, is the highest sea cliff on Lanai. It faces southwest, the direction from which generally the most severe storms reach Lanai, whose windward coasts are protected by Maui and Molokai. Pali Kaholo has been undercut by the waves in places, and has very few talus fans at its base, attesting to the efficiency of the waves in eroding and removing blocks of basalt. Beyond Kaumalapau the shoreline remains as sea cliff. It is mainly low in the section north to Honopu Bay, then increases to local heights of more than 300 feet as the coast trends in a concave seaward curve northwest to Kalaeahole. From that vicinity the coast is again a lower sea cliff, curving convexly north and northeast past Kaena Point to the beginning of Polihua Beach.

A bench that is cut in the lava bedrock at heights of a few inches to a few feet above sea level is present along several sections of the south and west sea-cliff coasts of Lanai. In places the bench is as much as 100 feet wide, and it has been attributed by Stearns (1935, 1938) to be due in part to wave erosion at present sea level and in part to wave erosion of the past when sea level stood about 5 feet higher than it does now.

Stearns also reported that coral heads were growing in abundance off the south and west coasts, and that they could easily be seen on a calm day (Stearns, 1940a, p. 18). There is no growth in any one place, except near Kamaiki, that is concentrated enough to constitute a fringing reef. Sea stacks are common along parts of the coast. We can report no further details of this offshore area as it was only observed on several low passes by aircraft and not by boat.

Northeast coast (L-2). The hinterland of the north and east, or windward, coasts of Lanai is the overgrazed and eroded surface of the north and east flanks of Lanai volcano. The north end is called the "blown country"; it has a bizarre topography developed by wind erosion and deposition of the thick soil that covered the island before goats were introduced. From Kahokunui to

Awehi the hinterland is more deeply eroded, but principally by streams.

The shoreline of this coast is mainly depositional, and the most typical features are beaches. Polihua Beach, at the western end of this coast, is an excellent beach with a large quantity of calcareous sand, like so many beaches with northwest exposures on other islands. Eastward for several miles to Kahokunui at the delta of Maunalei Gulch the coast has alternating stretches of beach and of beachrock, and generally has areas of dunes behind the beaches. There are patches of mud and gravel at stream mouths.

From Kahokunui to Halepalaoa Landing the coast has a narrow beach of fine sand chiefly of detrital origin. There are small deltas of pebbles and cobbles off the stream mouths. Lae Hi is a point of eolianite, and there are two old fishponds farther east. South of Halepalaoa the beach is chiefly calcareous sand, and that part beyond Makaiwa Point is an eroding coast in contrast to the coasts northwest of there. Even along the eroding coast there are still some fairly wide beaches, as at Lopa and at Kahemano. The beach becomes coarser grained to the southeast, and as the reef narrows past Naha the shore becomes a pebble and cobble beach which continues past Kapoho delta where a sea cliff begins.

The area off the northeast coast is one of the longest stretches of fringing reefs in Hawaiian waters. In several places the reef is more than 3000 feet wide. The reef-flat has considerable silt and sand on it that has washed from Lanai, but there is active growth along the reef margin. The reef and Molokai and Maui farther to the windward protect the northeast Lanai shoreline from storm waves, so that the small stream deltas there are preserved rather than eroded away.

Maui

Introduction. The shoreline geology of Maui, the second-largest island in the State, is due to the same factors of rock types, energy sources, and geologic history that shaped the shoreline features of the other islands. Stearns and Macdonald (1942) presented a general geologic report of Maui. Maui was built by the two volcanoes, West Maui and Haleakala. West Maui is deeply dissected by radial drainage patterns cut into its main shield-building basalt lavas, named the Wailuku volcanic series, with thin scattered cappings of the thicker, more siliceous lavas of the Honolua volcanic series. After a long period of erosion, four small secondary eruptions built the cinder cones and associated volcanic rocks of the Lahaina volcanic series. The highest sea cliffs, and a few reefs, are along the Honolua series coastline.

Haleakala, or East Maui, has its primitive basalts of the shield-building stage, the Honomanu volcanic series, nearly buried by the succeeding more siliceous lavas of the Kula series. Kula flows, banked westward against the West Maui volcano, have built the Maui isthmus. The Kula volcanic series has the highest sea cliffs around Haleakala. After an extensive erosional episode, volcanism was renewed on Haleakala in the form of cones and flows of the Hana volcanic series. These alkalic rocks are most abundant on the east and southwest rift zones of Haleakala.

The effects on Maui of several changes of sea level in the Pleistocene are similar to the effects on other islands. Old sand dunes, that now are generally lithified, spread over the northwest part of the isthmus where sand was exposed on old reef surfaces during a lower stand of the sea. The south shore of the isthmus is a barrier beach. Most beaches are on the isthmus coasts or extend away from there. These long beaches suffer greatly from erosion and beachrock formation. Another poor, long beach is the narrow, pebbly beach of the Lahaina-Olowalu coast. Beaches near Kaanapali are of moderate size. Most other beaches are pocket beaches.

The length and diversity of coastline has led to a classification having many subdivisions. For the sake of simplicity some are combined to give the total of 11 sections discussed below.

Waihee coast (part of M-1). The coast from one-half mile northwest of Waihee south through Kahului Harbor is a depositional coast dominated by Waihee Reef and Iao Stream. It lies between a sea-cliff coast to the northwest and a low, eroding sandy coast to the east.

West Maui lavas, mainly of the Wailuku series, form rugged terrain behind hills a few hundred feet high of dissected alluvial fans and older dunes. Lowlands are alluvium and shoreline deposits. This coast and the one next cited (Paia) are the most thickly populated ones on Maui.

Although it is low, the northernmost part of this coast has no beaches. Off Waihee Farm and to the southward, however, the consolidated and unconsolidated alluvium has bordering it a narrow beach of poorly sorted sand and gravel as coarse as cobbles. There is an increase in the detrital portion of the sediment approaching Iao Stream along the barrier beach fronting Paukukalo Swamp. The delta of Iao Stream makes a distinct bulge, Nehe Point. Kahului Harbor has beaches of varying width, except at its east end where there are cliffs a few feet high, cut into the old dunes, and harbor works.

Waihee Reef is the most prominent offshore feature along this coast. North of Waihee Point there is no reef, and south of Waihee Point all the way into Kahului Harbor the reef narrows to half its width off Waihee. The eastern part of Kahului Harbor has been dredged. Most of these inshore areas are sediment-covered.

<u>Paia coast (part of M-1)</u>. The coast from the east breakwater of Kahului Harbor east to Hookipa Park is low with several beaches, and generally has a strip of dune sand along the shore. The hinterland is the gently dissected lower northwestern slopes of Haleakala, with rocks of the Kula series underlying patches of alluvium and the extensive sugar cane lands.

The beaches are very discontinuous, broken naturally by outcrops of beachrock and artificially by groin systems. Lines of beachrock awash at the waterline as much as 800 feet offshore show that the historical record of beach erosion is merely the latest stage in a process operating over the last few hundred years. Kanaha Pond is a lagoon behind the barrier beach at Kaa.

Spartan Reef, off the airport area, is the widest section of shallow water. East of Maui Country Club the reef width commences to taper, and it disappears near Hookipa Park. The reef surface is very irregular, both in topography and in the distribution of sand pockets on it. Some of the sand lies in strips crossing the reef, but owing to the high surf at nearly all times it could not be determined how closely these features resembled the Oahu sand-filled channels.

<u>Koolau coast (small part of M-1; part of M-3)</u>. A lengthy stretch of the north coast of Haleakala, from Hookipa Park to Nahiku, is moderately high sea cliff. The hinterland of this coast is Kula lavas, except in a few deep canyons where the underlying Honomanu lavas are exposed, and at Keanae Valley, down which some Hana series lavas flowed into the sea.

The sea cliff is irregular, broken by a number of bays that are partly-drowned river valleys. Some bays have shingle pocket beaches. The cliff is less than 100 feet high at its western end, but rises to 400 feet in height near Honomanu Bay. The broad two-mile-wide headland at the mouth of Keanae Valley is built into the ocean by flows that spilled from Haleakala through Koolau Gap and down the ancestral Keanae Valley. Keanae Point proper is the latest of at least five flows. Its sea cliffs are about 5 to 10 feet high.

A boat was not operated off this coast. Small islands isolated by erosion from the sea cliff are common. These sea stacks or stack rocks, as they are called, are associated with sea caves and an arch at Pauwalu Point.

Hana coast (part of M-3; part of M-4). From Nahiku to Muolea the hinterland is young lava flows and cinder cones of the Hana volcanic series in their type locality. Some of the slopes on these lavas near the coast are as gentle as 200 feet to the mile.

Hana Bay is the largest of several small bays along the coast. The bays lie between young flows that project into the ocean. Most of the shoreline is low sea cliff that is as much as 200 feet high at Kapukaula, but mainly 20 to 30 feet high from Ulaino to Muolea. Cinder cones at the shore are Kauiki, the south border of Hana Bay, and Ka Iwi o Pele, 1-1/2 miles south of Kauiki. There are pocket beaches in several of the coves, with sediment grain-sizes ranging from small rounded boulders 10 to 12 inches in diameter at Kainalimu Bay to fine sand on Hana Beach.

Offshore there are numerous small sea stacks of which Alau Island is the largest. The distribution of lava rock, coral, and sediment is very patchy, and there is no length of broad reef-flat such as that which typifies the windward coasts of Kauai and Oahu.

Kaupo coast (part of M-4; part of M-5). From Muolea westward to Palaha Gulch, about 3 miles west of Nuu, the south Maui coast becomes drier and exposures of bedrock become more common. The broad promontories of Kipahulu and Kaupo were formed by landslide debris and late Hana series lavas that flowed from Haleakala down the broad and deep Kipahulu and Kaupo Valleys cut in the Kula series flows.

The shoreline reflects the distribution of lavas just described. Of five segments of coast, the easternmost, middle, and westernmost have sea cliffs cut in the Kula series. Sea cliffs decrease in height from a few hundred feet in the east to 40 or so feet at the west end. The two strips of Hana series coast generally have low sea cliffs. Beaches are rare on this coast, and mainly are shingle of coral and basalt pebbles.

Sea stacks, sea caves, and the presence of at least one sea arch attest to the coastline erosion. No reefs were observed, although isolated coral heads are abundant. There is virtually no sand on the bottom.

Southwest rift coast (part of M-5; part of M-6). The hinterland of the coast from Palaha Gulch to Kanahena, in Ahihi Bay, is a very rough surface of young lava of the Hana volcanic series which erupted from vents along or near the southwest rift zone of Haleakala. The flows, which are everywhere exposed at the surface of the ground because of the aridity that inhibits soil formation, dip about 800 feet per mile into the ocean. Flows forming Cape Kinau west of La Perouse Bay were extruded at some date between 1750 and 1790, and are evidence that Haleakala is dormant rather than extinct.

Most of the shoreline is a low sea cliff 10 to 40 feet high. La Perouse Bay has a cobble beach in the center and a sand beach at its northwest end. In addition to a single boat run by a field party that was made close to shore along the entire south coast of Haleakala, Mr. B. C. Oostdam studied the Cape Kinau area in detail. He reported a mixture of rocky and coral patches, with the greatest coral growth in 20 to 30 feet of water. Oostdam's observations are summarized in a later section of this report.

Molokini coast (part of M-6; part of M-7). Commencing with Puu Olai Beach, the coast northward from Kanahena to Kihei has several beaches and associated dune areas. The hinterland south of an unnamed gulch between Halo and Wailea is Hana series volcanic rocks, and north of that gulch it is Kula series with some alluvium and older dune areas.

The south half of this coast has a series of crescentic beaches between low sea-cliff lava points. The largest beach is south of Puu Olai cinder cone. Apparently Puu Olai is tied to the Maui coast by beach and ash deposits. The beach south of Keawalai church near Makena is one of the most popular small beaches in this part of Maui. The beach at Keawakapu and northward is more continuous, but rocky points are still present and in winter often much of the beach is lost. Along this coast considerable sand has been blown inland. The beach is narrow, but apparently quite stable along the low, broad bulge of the coast between Kaluaihakoko and Kalepolepo, and there are two, old fishpond walls on the reef there. Northward to Kihei, erosion is in evidence and patches of beachrock are exposed.

The sea bottom along this coast generally has patches of sand off the beaches. The gradient is steeper and sand is less common along the southern half of this section of coast. A fringing reef about 1500 feet wide between Kaluaihakoko and Kalepolepo has only a thin veneer of sand across its surface. Molokini Islet, a recent tuff cone formed by an undersea explosion from an eruption on Haleakala's southwest rift zone and now partly eroded by waves, is a conspicuous feature 2-1/2 miles west of Puu Olai.

Maalaea Bay (part of M-7). The barrier-beach coast of the north end of Maalaea Bay between Kihei and Maalaea is a small segment distinct from the coasts at either side. Its hinterland is the south part of Maui Isthmus, with gentle slopes of alluvium-covered Kula series rocks and some steep western slopes of old alluvial fans in front of the West Maui Mountains. Kealia Pond is a shallow lagoon whose limits change with periods of storm and drought. It was separated from the sea when the barrier beach formed, and it is slowly being filled by alluvium washed in from the north and sand blown in from the south.

The shoreline is a gentle arc of beach 3-1/2 miles long. The beach has been considerably eroded in recent years, especially at its east end. Beach-rock exposures are common all along the beach. There is an artificial small-boat harbor at the west end.

Offshore the Maalaea Bay bottom is generally sandy near the coast. Farther offshore the water is moderately shallow, with some shoal areas. These are sites of sparse coral growth under present conditions.

McGregor coast (part of M-7). The sea cliff coast from Maalaea by way of McGregor Point to Papalaua contrasts with the low coasts at either side. Bedrock is the south end of the West Maui Mountains, mainly lavas of the Wailuku volcanic series, but some ridges are capped with Honolua series lavas. The slopes dipping 900 to 1500 feet per mile are cut by several gulches.

A sea cliff extends from the small-boat harbor at Maalaea to Papalaua. It is low, and there are tiny pocket beaches, but to the west the cliff is higher. A terrace about 5 feet above sea level borders the base of the cliff in many places.

Several dozen sea stacks and rocks that barely are awash line this section of coast. Deep water occurs close to land, becoming shallower at both ends of this coast.

Lahaina coast (part of M-7; M-8). A narrow coastal lowland extends along the southwestern coast of West Maui from Papalaua past Olowalu and Lahaina to Kahana. The hinterland is predominantly basalt flows and dikes of the Wailuku volcanic series, but the Honolua series is represented by some more siliceous flows and lava domes, especially near Olowalu, and there are three small areas of Lahaina series cinder cones and associated lava. Along the part of this coast southeast of Lahaina the lower slopes of the West Maui Mountains have a thick cover of consolidated old alluvium, and that area also has some younger alluvium closer to the shore.

The total length of shoreline of this coast has more beach than any other feature, but most of the beaches are very narrow and pebbly. The two broad points of Hanakoo and Honokowai are small cuspate forelands separated by the cinder cone of Kaanapali. These two beaches are wider than others along leeward Maui, and although they may momentarily suffer erosion as they did in the 1963 winter Kona storms, their long-term history of the past few thousand years has been one of shoreline advance. Kahana Point may also be a cuspate foreland, even smaller in size, but air photographs do not show the characteristic old beach ridges.

In general there is water 50 or so feet deep close to shore along this coast, but the bottom flattens out to the broad, moderately shallow Lahaina Roads anchorage and across the Auau Channel to Lanai. Narrow reefs fringe the coast near Papalaua, at Olowalu, and from Makila Point past Lahaina to

Puunoa Point. Patches of reef and old beachrock are common at shallow depths off Hanakoo Point and Honokowai Point.

Northwest coast (M-9; part of M-1). This coast of high sea cliffs is one of the most scenic on Maui. The hinterland is partly basalts of the Wailuku volcanic series and partly Honolua series massive flows of more siliceous layers. Prominent coastal hills are Puu Kaeo, a Wailuku series cinder and spatter cone, and Puu Koae and Puu Olai, bulbous extrusions of Honolulu series rocks.

The western third of this coast, facing northwest towards Molokai, is of Honolua rocks in their area of typical development. This is a coast of sea cliffs 20 to 100 feet high with several rocky points. In pockets between certain of these points there are good but small sandy beaches at Napili, Fleming's Beach, Oneloa, and Honokahau. Some other bays have tiny sand beaches. The beach at Honolua Bay is gravel. The middle third of this coast is of Wailuku lavas cut into sea cliffs 50 to 300 feet high, and small sand beaches occur only at Keonehelele and at Honokohau Bay. There are boulder and cobble beaches at the heads of several bays, especially at the mouths of streams. The eastern third of this coast is mainly cut into thick flows of the siliceous lava trachyte assigned to the Honolua volcanic series. These sea cliffs range up to 600 feet in height, and in several places the cliffs have near-vertical faces of 200 to 300 feet.

Only the western third of this coast was traversed by boat, and the bottom there has several small patches of reef. Honolua Bay has a reef, but apparently there are no reefs farther eastward. Sea stacks are common, and deep water lies close to shore.

Hawaii

Introduction. Hawaii is the largest island and has the longest coastline, but the regional aspects of coastal geology are not discussed in detail comparable with that outlined for the islands discussed above. The several reasons for this decision include the general inaccessibility of most of its shoreline, the rarity of good beaches, the lengthy discussion of coastal features by Stearns and Macdonald (1946, p. 51-57), and weather conditions that prevented boat operations off most coasts during visits over the past 1-1/2 years.

The geology of the island of Hawaii was mapped and described by Stearns and Macdonald (1946). Five major shield volcanoes have built the island. Kohala, at the north end, has a cap of more siliceous lavas, named the Hawi volcanic series, overlying an eroded core of shield-building basalt flows of the Pololu volcanic series. The main basaltic mass of Mauna Kea is named the Hamakua volcanic series, and some of its uppermost flows are more siliceous. Lying above thick deposits of the Pahala ash, with local evidence of minor amounts of erosion, is the Laupahoehoe volcanic series of interlayered basaltic and more siliceous lavas. A few of these flows are more recent than the small ice cap and glaciers that Mauna Kea had during the Pleistocene epoch. Hualalai volcano's last eruption in 1801 is the most recent of the basalt flows of the Hualalai volcanic series.

Mauna Loa and Kilauea are among the most active of the world's volcanoes, and each is made of basalts only. However, for Mauna Loa a long period of erosion, because of volcanic dormancy, separates a lower volcanic series, the Ninole, from the upper younger flows. These younger flows are called the Kahuku volcanic series if they are below the Pahala ash, and the Kau series, if above that ash. The Kau series therefore includes the historic flows from Mauna Loa. For Kilauea the basaltic lavas that are capped by Pahala ash are known as the Hilina volcanic series, and the upper series including historic flows is the Puna volcanic series. There are few exposures of rocks older than the Pahala ash on Mauna Loa and Kilauea. Fault scarps are common on the Kau and South Kona coasts of these two volcanoes.

Geologic features of the coastline vary from area to area depending on the volcanic eruptions and faulting, and on the erosional history of the major volcanoes. Seven coastal areas are discussed in the sections that follow.

Hamakua coast (part of H-5; part of H-1). The northeast coast of Mauna Kea, from near Waipio Valley to Hilo Bay, is a sea cliff 100 to 200 feet high. The hinterland is the constructional slope of Hamakua volcanic series lava flows, cut by valleys of moderate depth radiating from Mauna Kea. Some younger flows, of the Laupahoehoe series, have run down the slopes towards the sea, actually entering it at some places, such as at Laupahoehoe Point itself.

The shoreline is predominantly sea cliff, with a few small boulder beaches in small coves. A wave-cut bench about 25 feet above sea level that marks a higher stand of the sea in the Pleistocene has such old shoreline features as sea caves and arches along it. Also present along much of the coast is a beach or terrace about 5 feet above mean sea level. This beach is usually awash from the trade wind-driven waves.

Hilo coast (part of H-1). The broad re-entrant between the eastern lobes of Kilauea and Mauna Kea volcanoes has had deflected into it large volumes of Mauna Loa lavas; these have built out the coast to a broad bulge from Hilo to Leleiwi Point to Keaau. Hilo Harbor is now a new re-entrant between this recent lobe from Mauna Loa and the previous one. The hinterland of Kau volcanic series basalts is one of the lowest coastal areas on the island.

The shoreline is highly irregular, representing the surface of flows that have been little altered by the waves. Locally there is some evidence of coastal erosion, such as the very low sea cliffs near Leleiwi Point, and of deposition, such as the small beaches of Papai and Keaau.

Puna coast (part of H-1; part of H-2). The coast from Keaau via Cape Kumukahi to Kalapana is partly low sea cliff and partly the constructional surface of recent lava flows. The hinterland is the prehistoric and historic basalt flows of the Puna volcanic series erupted from the east rift zone of Kilauea.

The shoreline is irregular from clinker masses, collapsed lava tubes, and other primary structures of lava flows where later prehistoric and historic flows entered the ocean. In addition, the coast for a few miles to either side of Pohoiki is irregular because it sank 3 to 6 feet during the severe 1863 earthquake. As the waves continue to modify these coasts the rough outlines will be smoothed and a sea cliff cut like the cliffs west of Opihikao. Where some flows entered the ocean, explosions caused by the generation of steam from molten lava in contact with water ripped apart the chilling advancing edge of the flow. The resulting fragments of black basalt glass often formed a cone at the shoreline (littoral cone), and waves have eroded and redeposited these glassy sands, making black-sand beaches. The best known of these is Kalapana. Actually, Kalapana Beach is now chiefly cobbles because the sand has been washed away or blown inland into dunes, and tourists are taken to adjacent Kaimu Beach which still has sand in the summer months and at the southwest end even in winter months. Both Kalapana and Kaimu were formed from glass grains from the lava flow of about 1750 that entered the ocean east of Kaimu. Black sand beaches were also formed by the 1955 and 1960 Puna eruptions. The repopulation of the sea bottom near these flows is being studied by Professor Townsley of the Zoology Department of the University of Hawaii.

Kau-South Kona coasts (part of H-2; H-3). The coast from Kalapana around Ka Lae to Keawekaheka Point near Kealakekua Bay is a long one that could be further subdivided if the need arose. However, since the coast has few inhabitants or visitors, and since it has essentially the same features, it is treated here as a unit.

The hinterland of this coast is the southern slopes of Kilauea and Mauna Loa volcanoes, and the western slope of Mauna Loa as well. Exposed rocks are mainly the Puna and Kau volcanic series, but some older rocks are present too. Major sets of faults that have trends generally paralleling the flank of the volcanoes, and therefore paralleling the sea, are present along this coast except where the southwest rift zone of Mauna Loa bulges into the ocean northwest of Ka Lae, and at a few other places. Nearly all the coast is sea cliff, and the cliffs are especially high where the faults are both close to and parallel the sea. For example, Kapukapu is a high cliff, but both to the east and southwest the faults trend inland at an angle and the coast is flatter. Pali Kaholo in South Kona follows a fault, but north of Hookena and south of Milolii there is no fault and the coast is flatter. Several littoral cones from prehistoric and historic lava flows are present along the shoreline, and some have adjacent black-sand beaches. A beach about 2 miles northeast of Ka Lae is a green-sand beach, colored by its predominant content of olivine grains.

North Kona coast (small part of H-3; part of H-4). North of the end of the fault-controlled sea cliff of Kealakekua Bay there begins a low coastline that extends northward to Kawaihae Harbor. Most of the hinterland is recent lava flows of Hualalai, but some flows both to the north and south of Hualalai came from Mauna Loa, and the east side of Kawaihae Bay is bordered by Mauna Kea lavas. There is very little stream erosion of the surfaces of these flows.

The shoreline resembles that of North Puna in being highly irregular from primary volcanic structures, or having sea cliffs a few feet high. However, this Kona coast has more beaches and the beach sand has a high calcareous content. The small beaches generally are pocket beaches in the slight bays formed between adjacent flows that project into the ocean. Kailua Bay and Kiholo are good examples. Storm beaches lie several yards inland in patches from Kailua to Kawaihae. The best beaches on this coast, and indeed the best on the island, are along the short length of coast between Puako Bay and Kawaihae. This length of coast is older than the coast to the south and some intermittent streams enter small bays. The greatest part of the sand comes from marine organisms that live more abundantly offshore in these shallow waters than elsewhere on the island of Hawaii where submarine slopes are steeper. The fringing reef that has been utilized in part for the Kawaihae breakwater is the largest of the very few shallow reefs around Hawaii Island.

Kohala coast (part of H-4; part of H-5). The west and north slopes of Kohala volcano from Kawaihae to Pololu Valley have sea cliffs of moderate height, especially on the windward coast and at places on the west coast where the thicker lavas of the Hawi volcanic series cap the older Pololu series. Patches of marine conglomerate from the 5- and 25-foot shorelines lie close to the shore north of Kawaihae. The absence of reefs off this coast, even though it is an old one, has been attributed by Stearns and Macdonald (1946, p. 53) to its steepness and to the rapid rate at which sea level rose after the melting of the great continental ice sheets.

Waipio coast (part of H-5). The coast between Pololu and Waipio Valleys rises in a sea cliff that is as high as 1400 feet. Erosion is principally in basalts of the Pololu volcanic series on the windward coast of Kohala volcano. Four deep valleys, cut to a lower stand of the sea and now having deeply alluviated floors, owe their development to these factors (Stearns and Macdonald, 1946, p. 47): (1) they were cut in a segment of Kohala dome sheltered by fault scarps from younger lavas that otherwise would have filled the young valleys; (2) the Pololu lavas are thin and basaltic, whereas much of the remainder of Kohala volcano has a capping of Hawi lavas that are more resistant to erosion; (3) the valleys drain the windward and therefore wettest slope; (4) the valleys are tapping ground water that is trapped in high compartments in the dike complex of Kohala volcano, and so have perennial flow.

The shoreline is chiefly sea cliff, but part is landslide deposits now being reworked by the waves. Sand beaches occur at the valley mouths, with dunes blown inland as high as 50 feet. Offshore there are several sea stacks, and near Honokanenui, and on either side of Waipio Valley, there are small fringing coral reefs.

Other Islands

Niihau was visited only once, near the end of the project. The center of the eastern coast of Niihau is a sea cliff, cut in older lavas, with moderate-sized beaches of calcareous sand north and south of it. A coastal plain across the south end of the island is constructed of younger lavas overlain by lithified old dunes, now being covered by active dunes. The western coast has the large beach and associated dunes of Keawanui Bay along its northern half, and smaller beaches southwest of there. Stearns (1947) and Macdonald (1947b) have described the geology of Niihau.

Kahoolawe was not visited in this study. Stearns reported that the shoreline of Kahoolawe is mainly sea cliff with a few small beaches on its west side (Stearns, 1940a).

DETAILED BEACH ANALYSIS

Introduction

Beaches are the natural shoreline features that not only are the most important, from the standpoint of man's utilization, but also, show the greatest changes over short periods of time. This section of this report is a detailed description of 90 significant Hawaiian beaches.

Several factors entered into the selection of these beaches. Primarily, the list includes all the beaches that are extensively used. Among that group are several with existing public beach parks, private parks, and resorts. Some additional beaches are poor and tiny, but nevertheless these have a public beach park, and some are extensive with abundant sand, but they are not as yet developed for public or private use. Another group of beaches is comprised of those which were chosen rather arbitrarily from among their neighbors as being representative of the beaches along a particular segment of the coast. The analysis of these 90 beaches, therefore, provides a set of 90 examples that cover the range of all the beach types in the State.

For each, there is a written description of the location and dimensions of the beach, the changes measured in the one and one-half years of this project, and any changes which occurred earlier that can be determined from air photographs or from interviews with local inhabitants. Included is an analysis of the beach sand, its composition, grain size, and other parameters. The hinterland and offshore areas are described in relationship to the particular beach.

Key to Illustrations

Supplementing each description of a beach is an illustration sheet with several figures, described as follows. The name of the beach is keyed to the Planning Department maps discussed in the preceding section on Geology of Coastal Segments.

A sketch map shows the shape of the beach and its orientation. Size can be determined from the bar scale, as the maps are drafted at varying scales to fit the illustration sheet. Cliffs, rivers, dunes, areas of sandy bottom offshore, and similar features adjacent to the beach are shown.

A topographic profile across the beach and the nearshore bottom also shows the nature of the rock or sediment. Onshore profiles were surveyed by transit, and offshore profiles were surveyed mainly by fathometer with plane-table and alidade control. In some instances where reefs or high-surf conditions prohibited the use of a boat, offshore topographic control was obtained from swimmers with stadia rods or lead-lines. All offshore profiles were compared with charts published by the U.S. Coast and Geodetic Survey. Most profiles were continued to 30 feet of water or 2000 feet seaward of the inner part of the beach. After correction for the state of the tide to our local datum, mean lower low water (mllw), profiles were drafted at a horizontal scale of 1 inch = 200 feet, and a vertical scale of 1 inch = 20 feet. This ten-fold vertical exaggeration emphasizes such small relief features as berms and reef edges. Near the shoreline are plotted the limits of change measured in the March 1962 through September 1963 period of this study. Except as noted, the profiles are all of summer-season 1963 measurements, for the sake of uniformity. The line of section, with the three-letter range designation of our present Institute of Geophysics system, is shown on the sketch map.

Two of the figures on the illustration sheet show the character of the sand. The distribution of the size of the grains in a reference sample of sand (usually from sea level at mid-beach) is shown by a histogram. The height of each bar is the percentage by weight of sediment in each unit of grain size. The limits of sand size are at 2 mm between fine pebbles (i.e., gravel) and very coarse sand, and at 1/16 (0.0625) mm between very fine sand and silt (i.e., mud when wet). The ten divisions shown for sand are technically known as 1/2-phi sizes based on Wentworth's size classification (Krumbein and Pettijohn, 1938). The divisions are based on a negative logarithm of the grain size. The position of the highest bars shows the over-all grain size, and the general shape of the figure shows the sorting of the sediment.

The composition of the sand is shown on an adjacent figure. The percentage by weight of the detrital portion, chiefly volcanic grains eroded from the land, is represented by the height of the black bar in the middle of the figure. The remaining white portion above is the percentage by weight of the calcareous grains that came from shallow-water organisms.

At the left of the center bar the detrital-grain composition is shown graphically, and at the right is shown the organic or calcareous-grain composition. The key to letters used for the components is as follows; the components themselves are described in the section on Origin of Sand.

Detrital		Organic	
D	Mud, or grains heavily stained with mud or iron oxides	H	**Halimeda**
W	Weathered rock fragments	A	Red algae
L	Fresh lithic, or rock, fragments (usually basalt)	M	Mollusks
G	Volcanic glass	C	Coral
O	Olivine	F	Foraminifera
K	Black minerals; magnetite, ilmenite, augite	S	Sponge spicules
P	Plagioclase feldspar	E	Echinoids
X	Unknown	X	Unknown

In a sand predominantly detrital, with only a few calcareous grains that could be found under the microscope, percentages would be biased by the low counts. In such cases the organic grain column is left blank, or a circled key letter indicates there were only traces of a component. A similar arrangement is shown for predominantly calcareous sands.

Kauai: by J. F. Campbell

Hanamaulu K-1. (Figure 1.) This is a 1500-foot-long by 35-foot-wide arcuate beach at the head of Hanamaulu Bay. No change in the width of this beach was noted during the period of this investigation. The south end of the beach is a barrier that partially blocks Hanamaulu River. The beach has a low slope and no prominent berms. The sand is fine grained and mainly calcareous in composition.

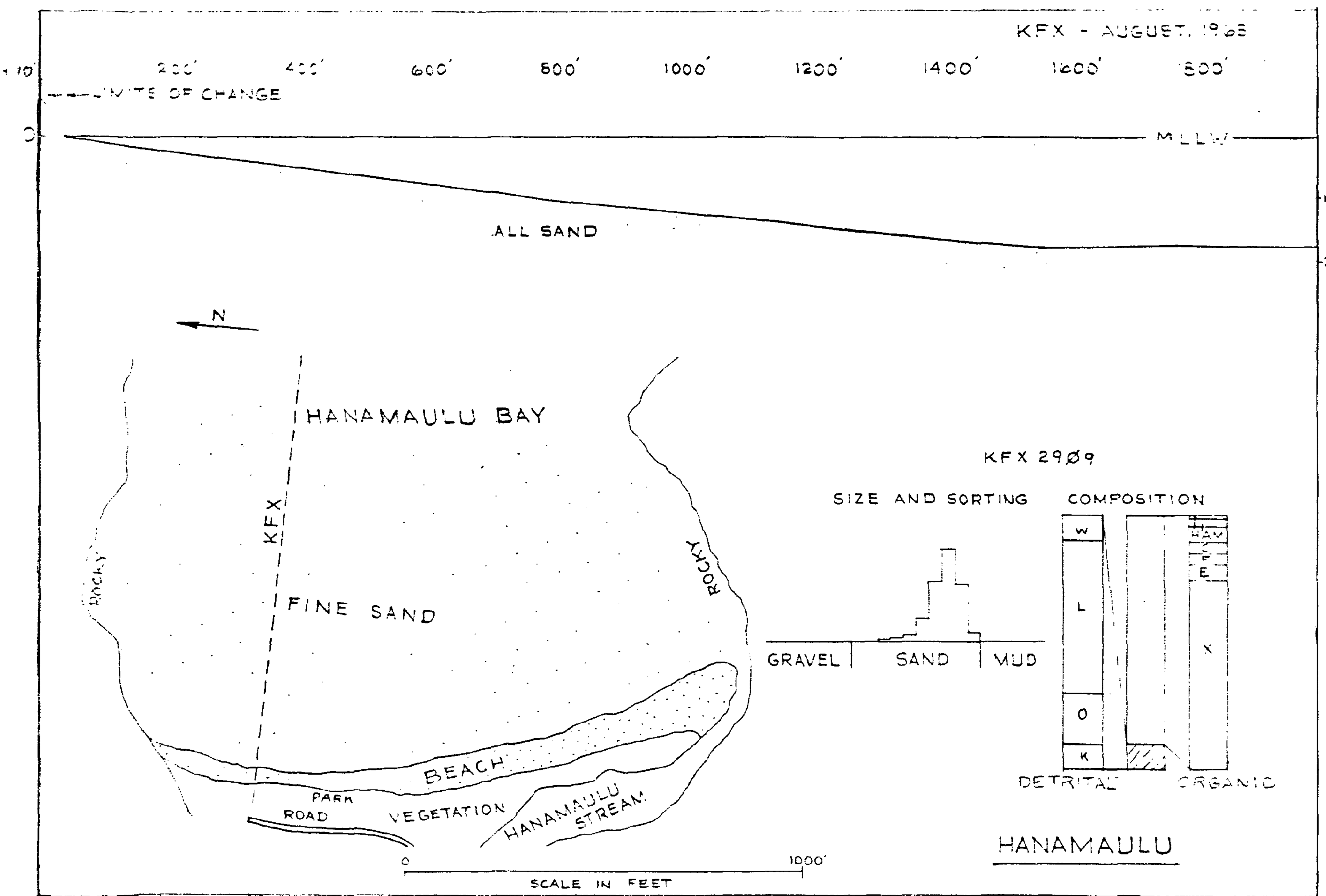

KFX - AUGUST, 1968
+10'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
0
MLLW
10'
20'
ALL SAND
N
HANAMAULU BAY
KFX
FINE SAND
ROCKY
ROCKY
BEACH
PARK
ROAD
VEGETATION
HANAMAULU STREAM
0
1000'
SCALE IN FEET
KFX 2909
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
K
E
X
DETRITAL
ORGANIC
HANAMAULU

Fig. 1

Offshore the bottom seems to be all fine sand, with reef patches near the rocky edges of the bay. There is a public park at the center of the beach, but dirty water due to stream discharge prevents this from being a popular swimming beach.

Nawiliwili K-1. (Figure 2.) Nawiliwili Beach (Kalapaki Beach) is an arcuate pocket beach at the mouth of Nawiliwili Stream, held by cliffs on the east side and a sea wall on the west side. The beach is about 1/4-mile long and is about the same width along its entire length. During the period of study, the width of the beach varied by about 50 feet, losing sand in the winter and gaining it back during the summer. The beach has a very gentle slope with a low berm that is often cusped. The sand is highly calcareous and of medium-grain size.

Back of the beach are the grounds of the Kauai Surf Hotel. Offshore the bottom is sandy and very good for swimming. There is a counterclockwise current in the bay, but this is never very strong unless the water is rough.

It must be noted that the name Nawiliwili is still used by many local residents for the small narrow beach near the mouth of Huleia Stream.

Poipu K-2. (Figure 3.) Of the beaches near Poipu the one investigated most thoroughly is the beach nearest the public park. There a 700-foot-long, sharply arcuate beach is held on the east by a rocky point, and on the southwest the beach is a tombolo (a strip of sand which connects one island to another). The beach is narrow at the neck of the tombolo and widens to the east, averaging about 70 feet in width.

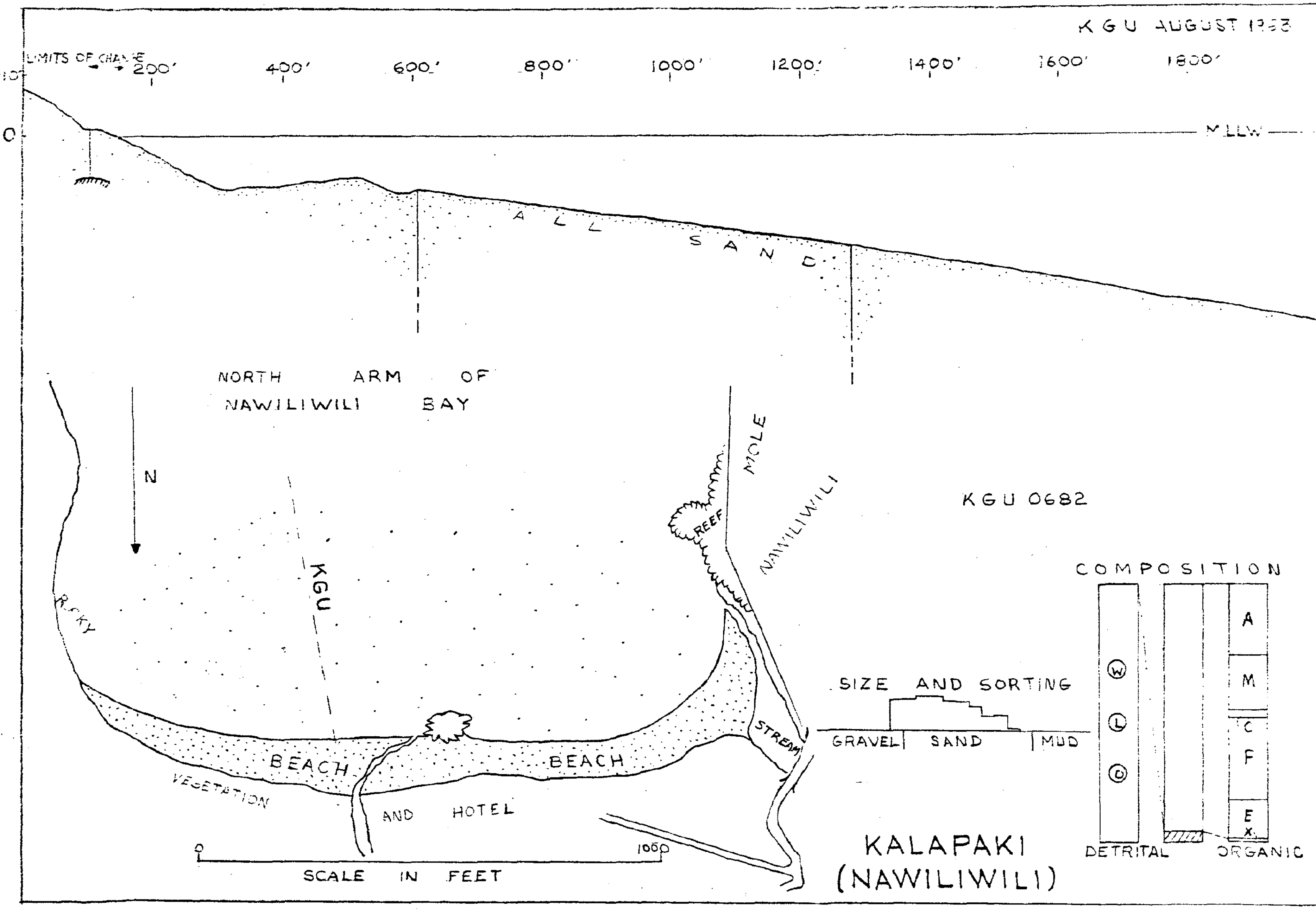
This beach is often moderately steep with no noticeable berm. The swimming is good inside the reef that fringes the coast, even though the water is not very deep. At the east end of the beach there is a public park with a pavilion.

The major change noted on this beach was growth after the Kona storm in January 1963. During the storm sand was washed from the west over the tombolo.

Hanapepe K-2. (Figure 4.) The barrier beach at the mouth of Hanapepe River is a 1/2-mile-long beach west of Port Allen in the harbor area of Hanapepe. In early 1962 this was an arcuate beach with an average width of 70 feet that narrowed to the west. Since that time the beach has undergone continual erosion and, when last seen in August 1963, it was everywhere eroded back to a boulder sea wall except at the mouth of the Hanapepe River where the beach is a bar that partially blocks the mouth of the river. The medium grained sand is predominantly composed of volcanic detritus deposited by the river.

There is a public park at the west end of the beach, but the beach is seldom used for swimming because the water is always dirty owing to suspended sediment transported by Hanapepe River.

Waimea K-3. (Figure 5.) A long, fairly wide beach extends from the Waimea River west to Kikiaola Small Boat Harbor. The foreshore slope varies from being steep in winter to being moderate during the summer. During the period of observation, the beach had at least one berm, and often had two. Most observations were made at the east end of the beach.



KGU AUGUST 1953
LIMITS OF CHANGE
+10'
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
-10'
-20'
-30'
ALL SAND
NORTH ARM OF
NAWILIWILI BAY
N
KGU
ROCKY
BEACH
BEACH
VEGETATION
AND HOTEL
REEF
MOLE
NAWILIWILI
STREAM
KGU 0682
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
D
A
M
C
F
E
X
DETRITAL
ORGANIC
0
1000
SCALE IN FEET
KALAPAKI
(NAWILIWILI)

Fig. 2

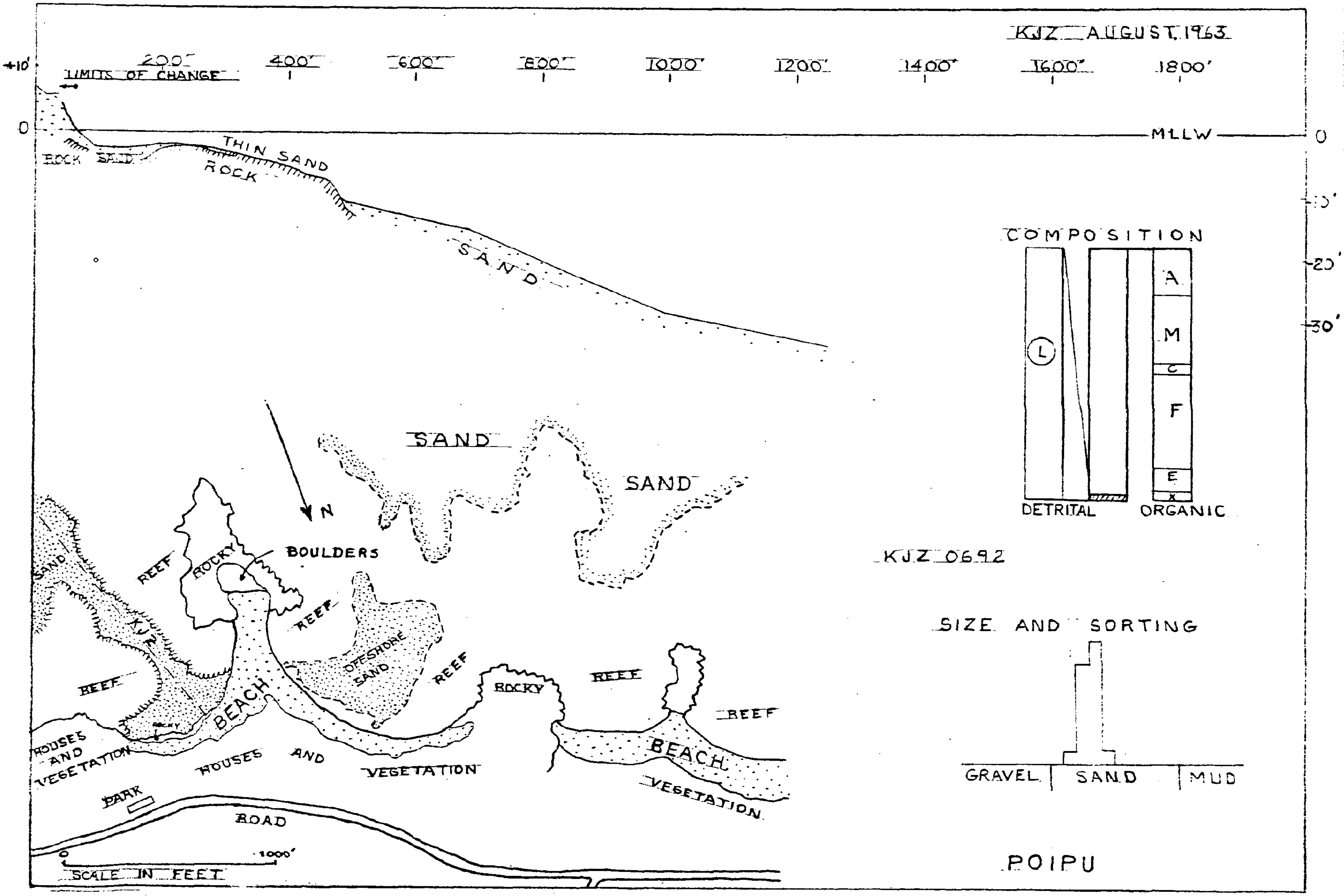

KJZ AUGUST, 1963
+10'
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
MLLW
0
-10'
-20'
-30'
ROCK
SAND
THIN SAND
ROCK
SAND
COMPOSITION
L
A
M
C
F
E
X
DETRITAL
ORGANIC
KJZ 0692
SIZE AND SORTING
GRAVEL
SAND
MUD
POIPU
SAND
SAND
N
BOULDERS
ROCKY
REEF
REEF
OFFSHORE SAND
REEF
ROCKY
REEF
REEF
SAND
KJZ
REEF
ROCKY
BEACH
BEACH
HOUSES AND VEGETATION
HOUSES
AND
VEGETATION
VEGETATION
PARK
ROAD
0
1000'
SCALE IN FEET

Fig. 3

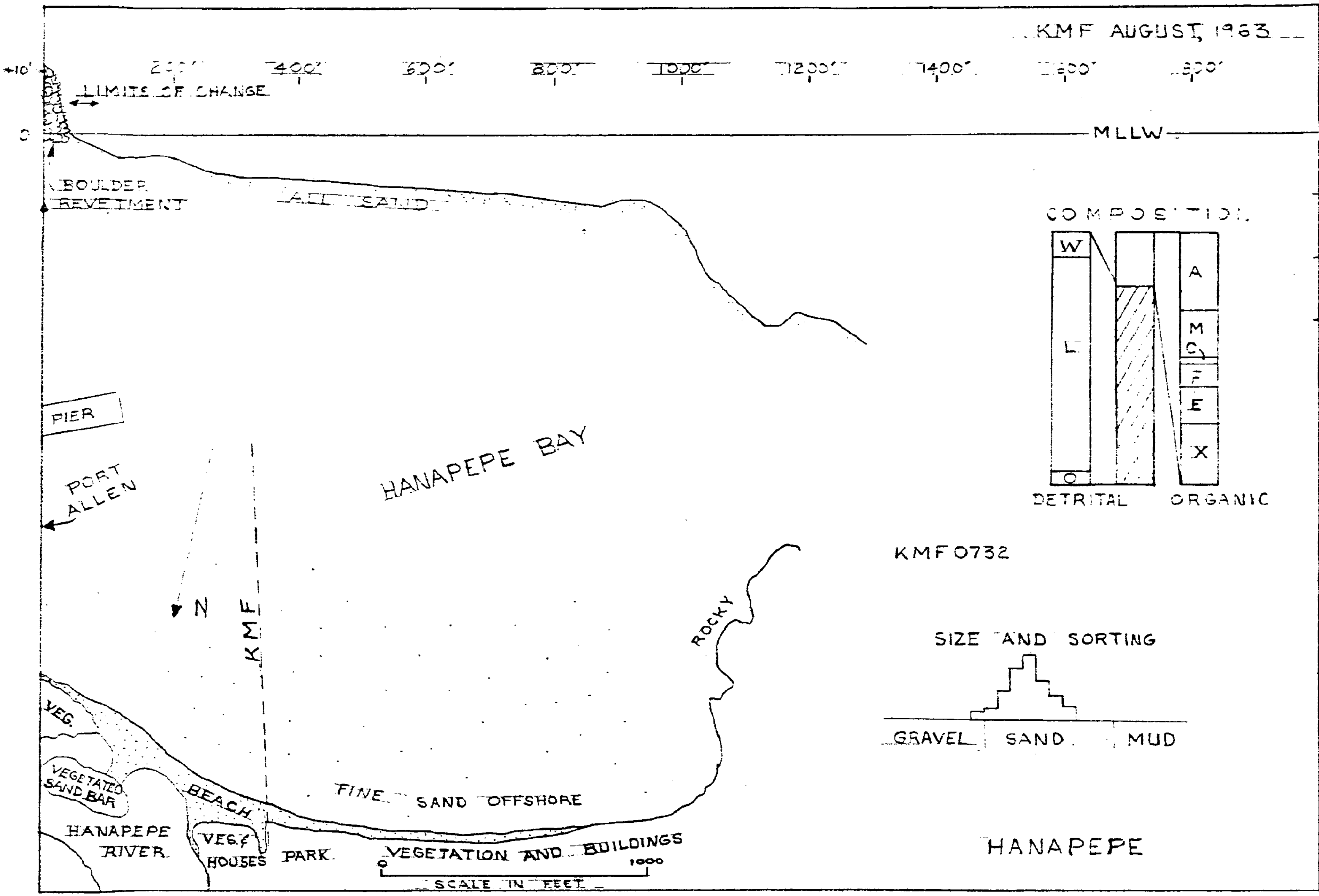
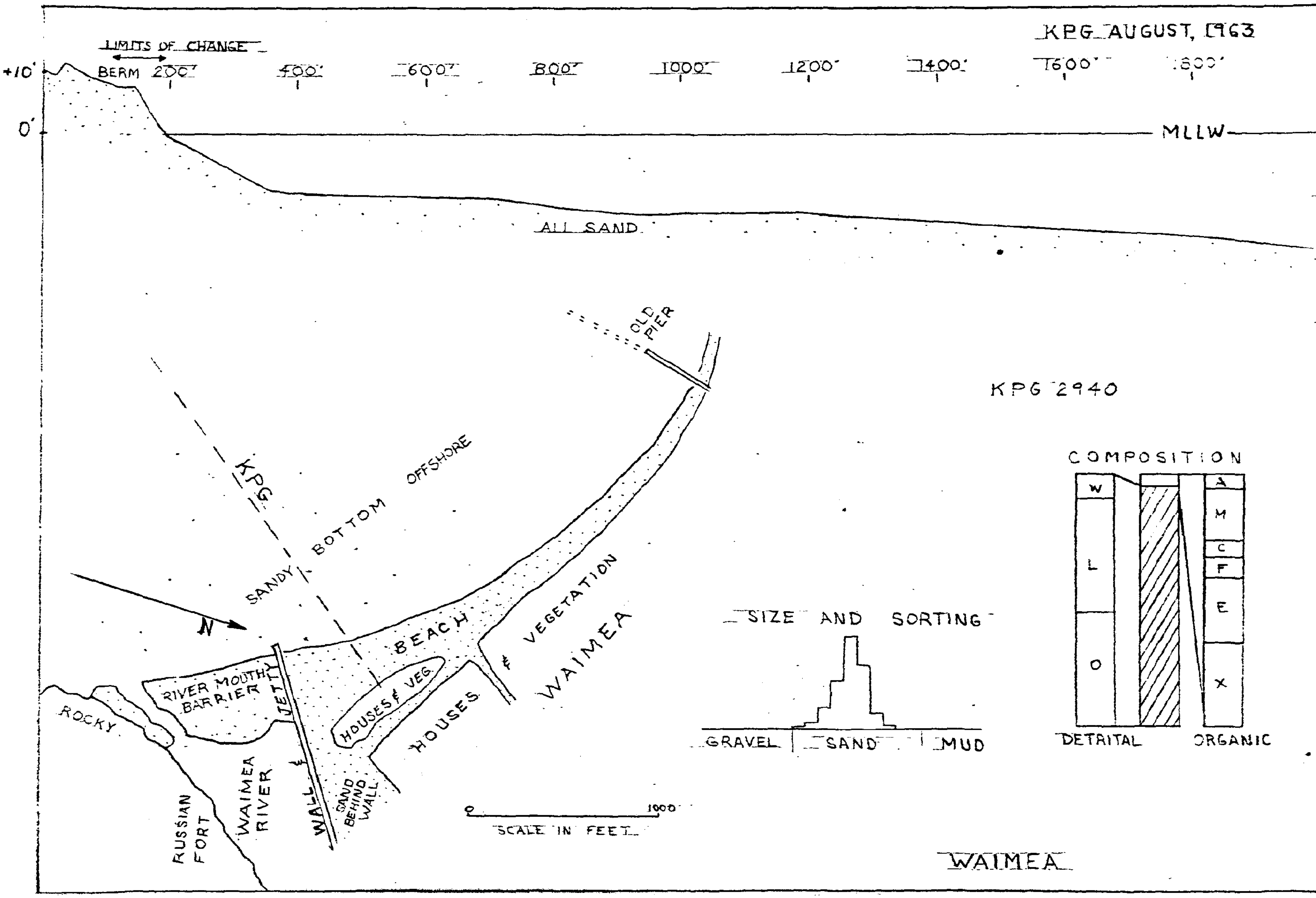

KMF AUGUST, 1963
+10'
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
MLLW
0'
-10'
-20'
-30'
BOULDER REVETMENT
ALL SAND
COMPOSITION
W
L
O
A
M
C
F
E
X
DETRITAL
ORGANIC
PIER
PORT ALLEN
HANAPEPE BAY
N
KMF
KMF 0732
ROCKY
SIZE AND SORTING
GRAVEL
SAND
MUD
VEG.
VEGETATED SAND BAR
HANAPEPE RIVER
BEACH
VEG.& HOUSES
PARK
FINE SAND OFFSHORE
VEGETATION AND BUILDINGS
0
1000
SCALE IN FEET
HANAPEPE

Fig. 4



KPG AUGUST, 1963
LIMITS OF CHANGE
BERM
+10'
0'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
0'
-10'
-20'
-30'
ALL SAND
OLD PIER
KPG 2940
KPG
SANDY BOTTOM OFFSHORE
N
BEACH
VEGETATION
WAIMEA
HOUSES & VEG.
HOUSES
RIVER MOUTH BARRIER
JETTY
WALL
SAND BEHIND WALL
ROCKY
RUSSIAN FORT
WAIMEA RIVER
0
1000
SCALE IN FEET
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
A
M
C
F
E
X
DETRITAL
ORGANIC
WAIMEA

Fig. 5

The beach is made up predominantly of grains of volcanic sand that are deposited by the Waimea River. There is a westward-flowing longshore current that moves the sand along the beach so that there is a gradual decrease westward in the percentage of volcanic components as the calcareous grains found in shallow water are added to dilute the volcanic component.

The water is usually dirty due to the muddy stream water discharging at the up-current end of the beach. Dirty water and the current are reasons this is a poor beach for swimming.

Kekaha K-3. (Figure 6.) This is a slightly arcuate 3/4-mile-long beach, part of the length of coast from Waimea River to Polihale that is mainly beach. The width of Kekaha Beach varies seasonally as the sand moves back and forth along the beach. During the winter the east end of the beach was 200 feet wide, whereas during the summer it was only 50 feet wide.

Back of the beach is a low dune ridge cut by a 2- to 3-foot high erosional scarp. Offshore there is a shallow reef that hinders swimming.

Beyond the patches of beachrock that make the west limit of Kekaha Beach, another beach continues around Kokole point, a cuspate foreland. This longer beach resembles Kekaha Beach in general profile of the beach and high calcareous content of the sand, but owing to its distance from good roads, it is used even less frequently.

Polihale K-3. (Figure 7.) Polihale Beach is a 3-mile-long and 300-foot-wide beach that extends from Barking Sands to the Napali cliffs. The beach is of uniform width except where it tapers away at the base of the cliff. Over the period of the study, the width of the beach varied by about 175 feet, being widest in the summer.

When the surf is high there are strong rip currents all along the beach, but when the water is calm this is a good swimming beach. Lack of facilities, including fresh water, prevents the use of this beach except by a few people. Nevertheless it is one of the finest beaches in the State of Hawaii.

Behind this beach are 100-foot-high dunes. The source of the abundant calcareous sand appears to be a broad bank at about 50-foot water depth offshore.

Haena K-5. (Figure 8.) An arcuate, 1/4-mile-long by 200-foot-wide beach narrows to the west where it terminates at a mound of boulders behind the reef. Back of the beach are low vegetated dunes. The foreshore is very steep in the middle of the bay at a beach park because there is no protection from the fringing reef that lies off the sides. The reef is the source of the dominantly calcareous sand.

During the period of study, there was always one berm, and often two, along this beach, and part of the time the berms were cusped. The beach varied in width by about 20 feet.

The swimming is very dangerous here whenever the waves are high. The reefs along the sides of the bay are popular for viewing reef fish.

Kepuhi K-5. (Figure 9.) Kepuhi Beach is a small beach on the broad point at Kepuhi, between Haena Point and Wainiha Bay, and is not to be confused with Kepuhi on the northeast coast of Kauai. Indeed, there are places named Kepuhi on other islands, too.

This beach averages 75 feet in width except for one wide area at its west end that is about 150 feet wide. In February 1963 this section

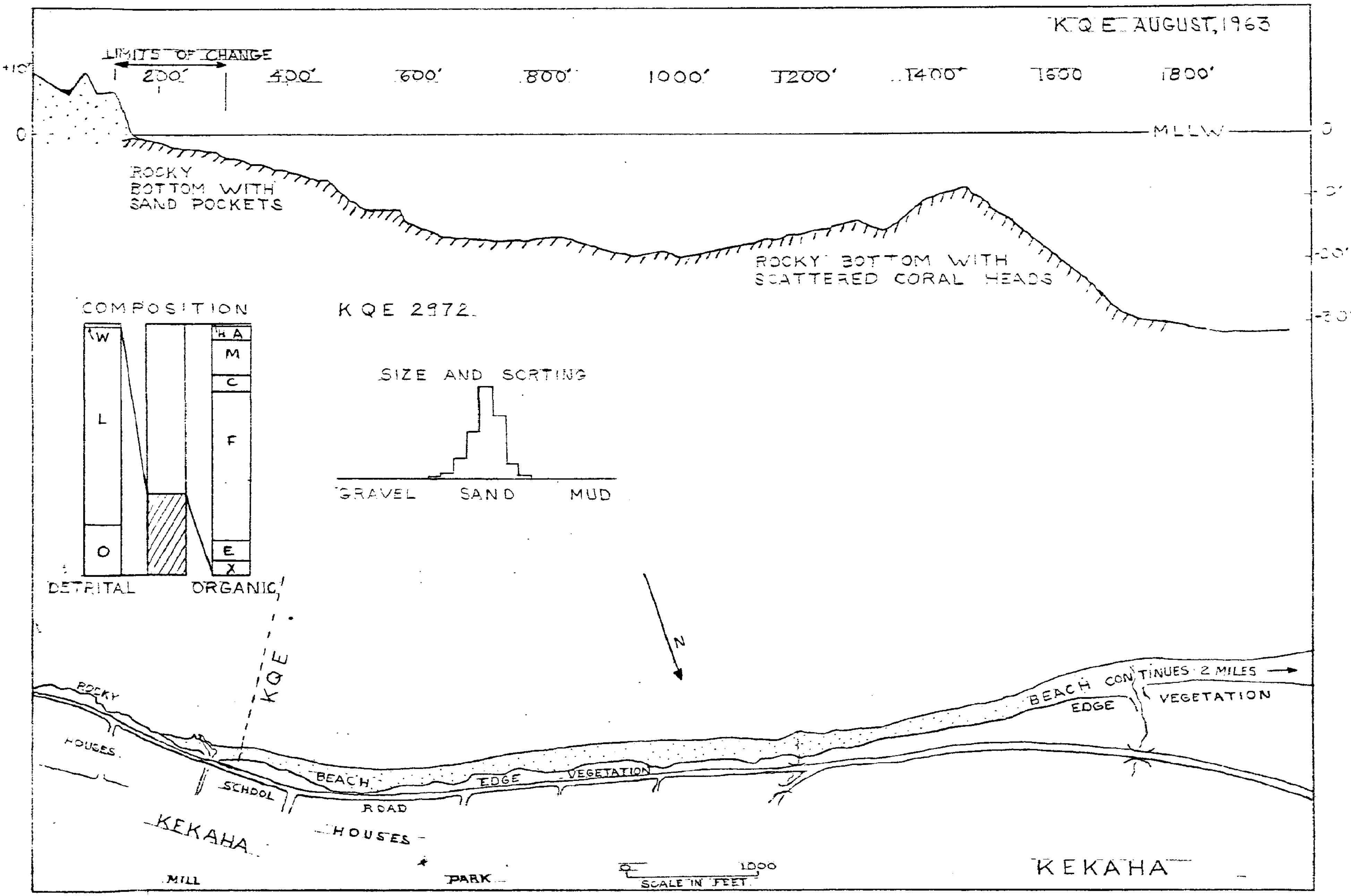

KQE AUGUST, 1963
LIMITS OF CHANGE
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10'
0
MLLW
0
-10'
-20'
-30'
ROCKY BOTTOM WITH SAND POCKETS
ROCKY BOTTOM WITH SCATTERED CORAL HEADS
COMPOSITION
W
L
O
H A
M
C
F
E
X
DETRITAL
ORGANIC
KQE 2972
SIZE AND SORTING
GRAVEL
SAND
MUD
N
KQE
ROCKY
HOUSES
BEACH
EDGE
VEGETATION
SCHOOL
ROAD
KEKAHA
HOUSES
MILL
PARK
0
1000
SCALE IN FEET
BEACH CONTINUES 2 MILES
VEGETATION
EDGE
KEKAHA

Fig. 6

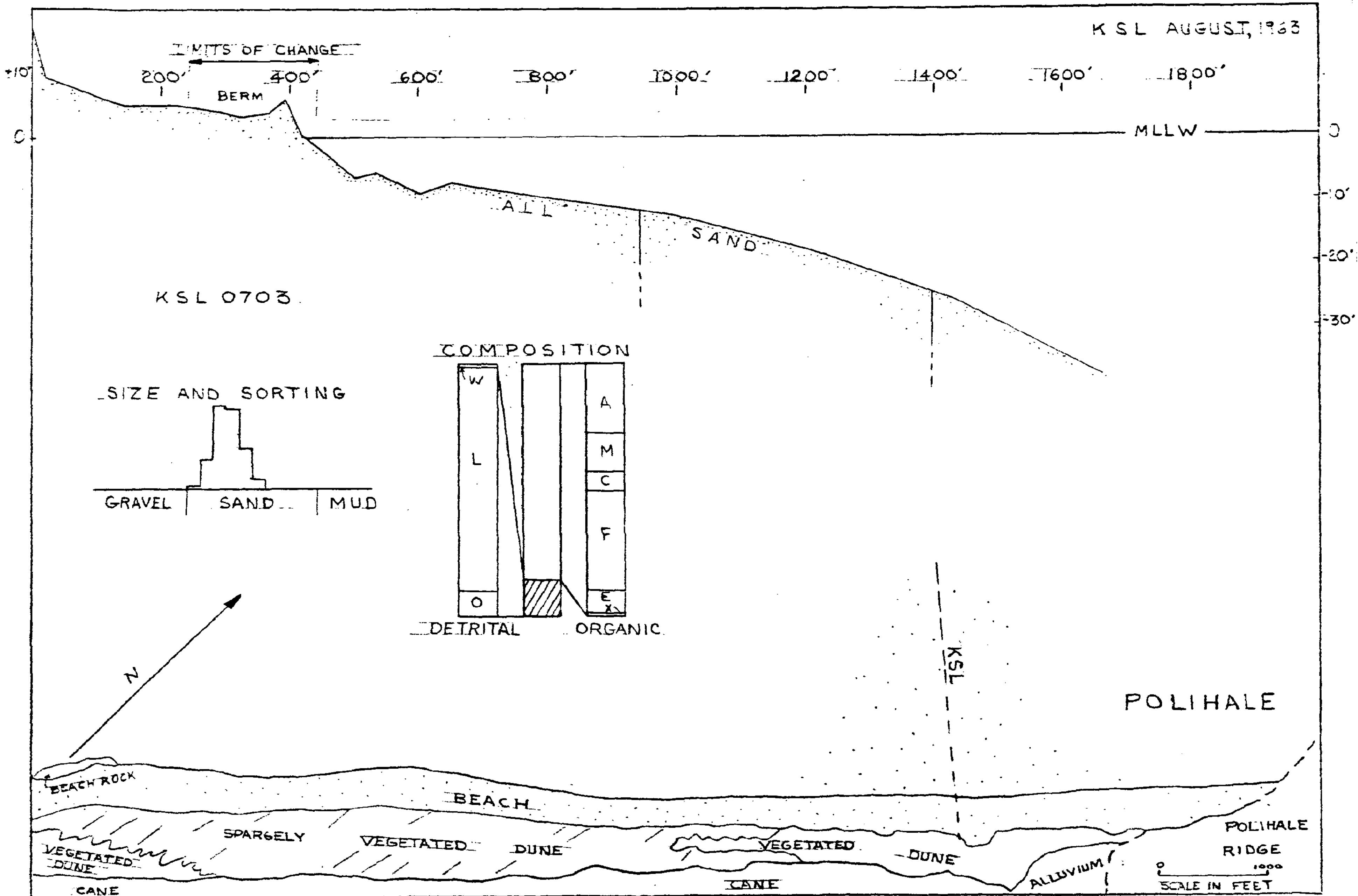

KSL AUGUST, 1963
LIMITS OF CHANGE
+10'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
BERM
0
MLLW
0
-10'
-20'
-30'
ALL
SAND
KSL 0703
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
A
M
C
F
E
X
DETRITAL
ORGANIC
N
KSL
POLIHALE
BEACH ROCK
BEACH
SPARSELY
VEGETATED
DUNE
VEGETATED
DUNE
VEGETATED DUNE
CANE
CANE
ALLUVIUM
POLIHALE
RIDGE
0
1000
SCALE IN FEET

Fig. 7

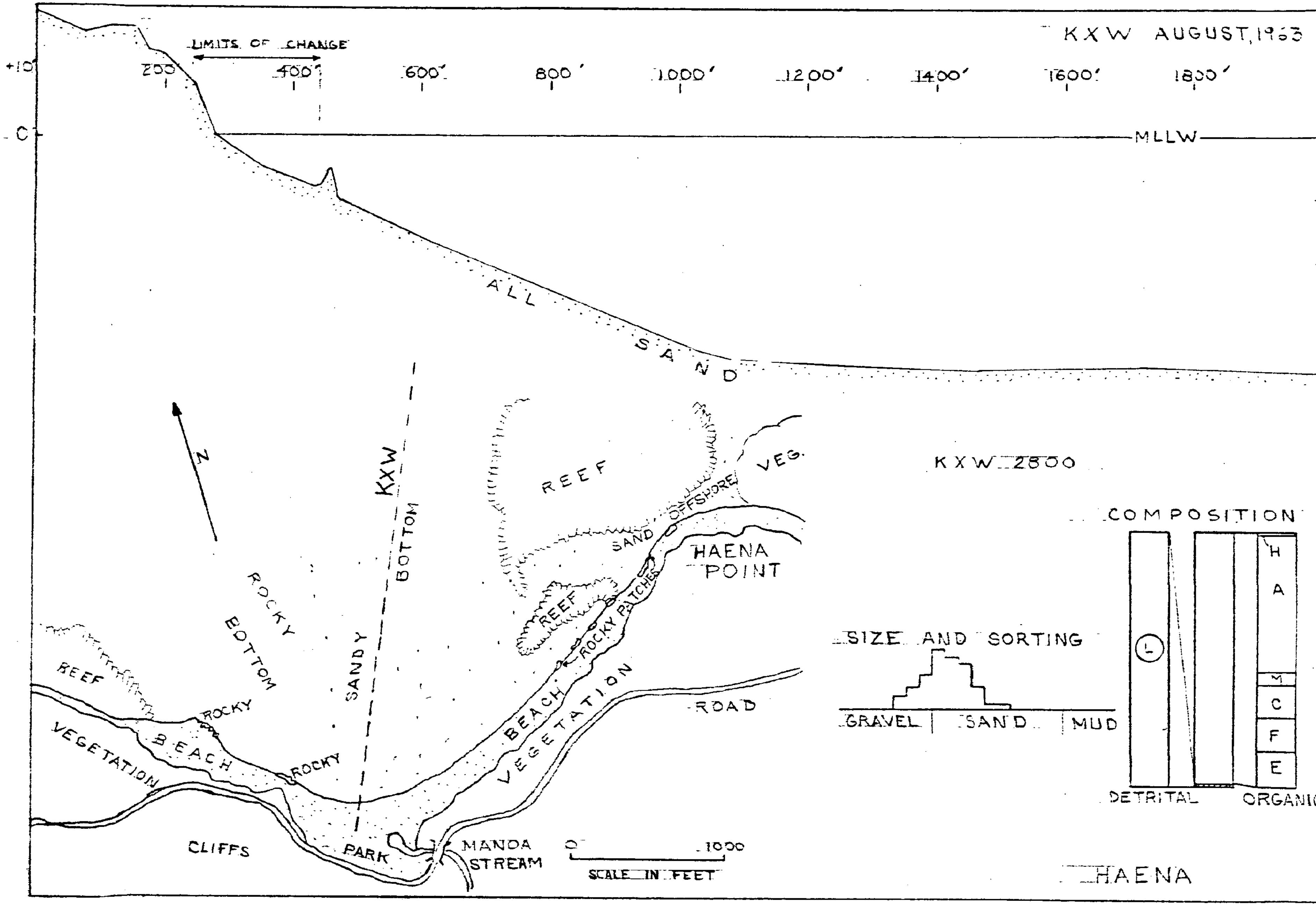

KXW AUGUST, 1963
LIMITS OF CHANGE
+10
200
400
600
800
1000
1200
1400
1600
1800
0
MLLW
0
-10'
-20'
-30'
-40'
ALL SAND
KXW 2800
COMPOSITION
H
A
M
C
F
E
L
DETRITAL
ORGANIC
SIZE AND SORTING
GRAVEL
SAND
MUD
HAENA
N
KXW
SANDY BOTTOM
ROCKY BOTTOM
REEF
OFFSHORE
SAND
REEF
ROCKY PATCHES
VEG.
HAENA POINT
BEACH
VEGETATION
ROAD
ROCKY
ROCKY
BEACH
VEGETATION
REEF
CLIFFS
PARK
MANDA STREAM
0
1000
SCALE IN FEET

Fig. 8

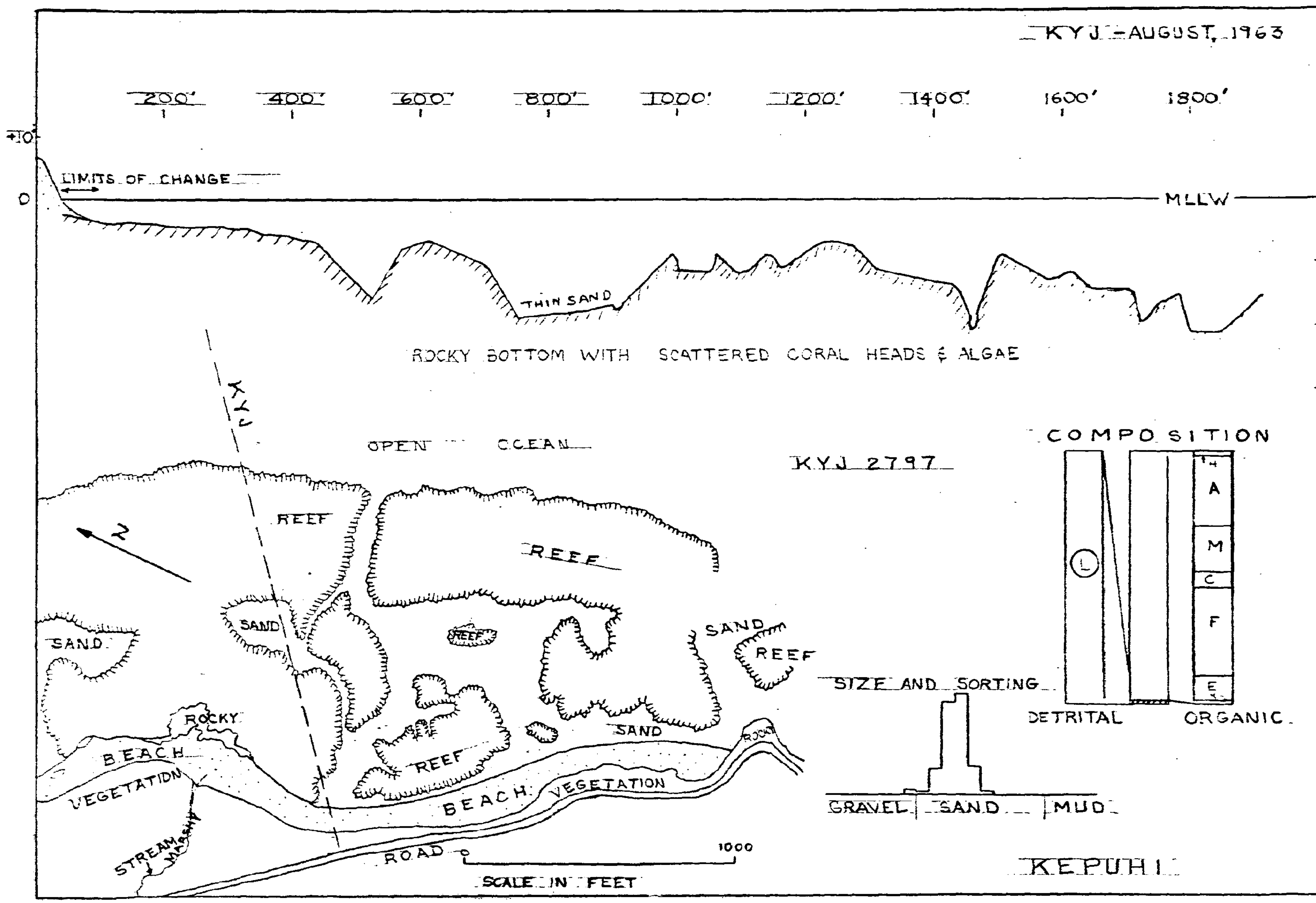

KYJ - AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10'
0
-10'
-20'
-30'
LIMITS OF CHANGE
MLLW
THIN SAND
ROCKY BOTTOM WITH SCATTERED CORAL HEADS & ALGAE
KYJ
OPEN OCEAN
KYJ 2797
COMPOSITION
L
A
M
C
F
E
DETRITAL
ORGANIC
SIZE AND SORTING
GRAVEL
SAND
MUD
REEF
SAND
ROCKY
BEACH
VEGETATION
STREAM
MARSH
ROAD
ROCK
1000
SCALE IN FEET
KEPUHI

Fig. 9

of coast on northern Kauai was badly eroded, but by August most of the sand had returned. The sand is highly calcareous.

This beach is protected by a shallow reef flat that prevents swimming except in a sandy-bottomed pool in the reef flat at its west end. This is a good place to swim except when high waves are washing over the reef.

Wainiha K-5. (Figure 10.) The 1/2-mile-long bay head barrier of Wainiha River on the north coast of Kauai is 200 feet wide at its west end where it is attached to bedrock, and narrows eastward to 100 feet at its east end. The beach is fairly steep and at one time showed two cusped berms. The profile of the ocean-side of the beach seemed to vary little during the investigation, but the inland side was modified by river-channel shifts.

The water here is dirty due to the discharge from the Wainiha River at the east side of the bay. Part of the sand is volcanic, carried by the river, but most comes from organisms that live on the adjacent seafloor.

Lumahai K-5. (Figure 11.) Lumahai Beach, east of the mouth of Lumahai River, is a 3/4-mile-long beach that varies seasonally in width. During the winter the sand moves from the west to the east. In August 1962 the west end of the beach was 350 feet wide, but, in February 1963, that part of the beach was gone and the waves were eroding the low dunes that had been behind the beach. During this same period the east end built out from 160 to 435 feet.

The foreshore is generally steep due to the large waves that strike it constantly. Generally, Lumahai has one or more well formed berms.

As many as six berms have been measured when the west end of the beach is wide.

The unspoiled setting of rugged topography and lush vegetation make Lumahai Beach one of the most scenic beaches in the State. However, its future development is problematical owing to the dangers of swimming on an exposed northern coast without a fringing reef.

Hanalei K-5. (Figure 12.) Hanalei Bay, the largest bay on Kauai, is nearly circular and opens to the north. Hanalei, Waioli, and Waipa Rivers have deposited detritus at their mouths, and these sediments, along with calcareous sands from offshore organisms, have been reworked by the waves into a two-mile-long beach. Hanalei Beach ends at Hanalei River at the east. At the west the beach becomes patchy and has abundant gravel where it narrows between Puu Manu headland and a reef which occupies the west side of the bay.

Hanalei Beach averages about 125 feet in width and shows a seasonal variation, being narrowest during the winter. The beach has a gently sloping foreshore that is often shaped by cusps.

There is a small public park and pavilion in the east-central part of the beach. The swimming here is good except when waves are high.

Kalihiwai K-5. (Figure 13.) Kalihiwai Beach is an arcuate beach about 1500 feet long that is a bay-head barrier of Kalihiwai River, on the north coast of Kauai. During the period of study, the beach varied in width from 85 to 165 feet. The beach was generally of uniform width except at its east end where it narrowed and graded laterally into a boulder beach at the base of a cliff that forms that side of the bay. The variation in width appeared to be seasonal, with sand moving out in

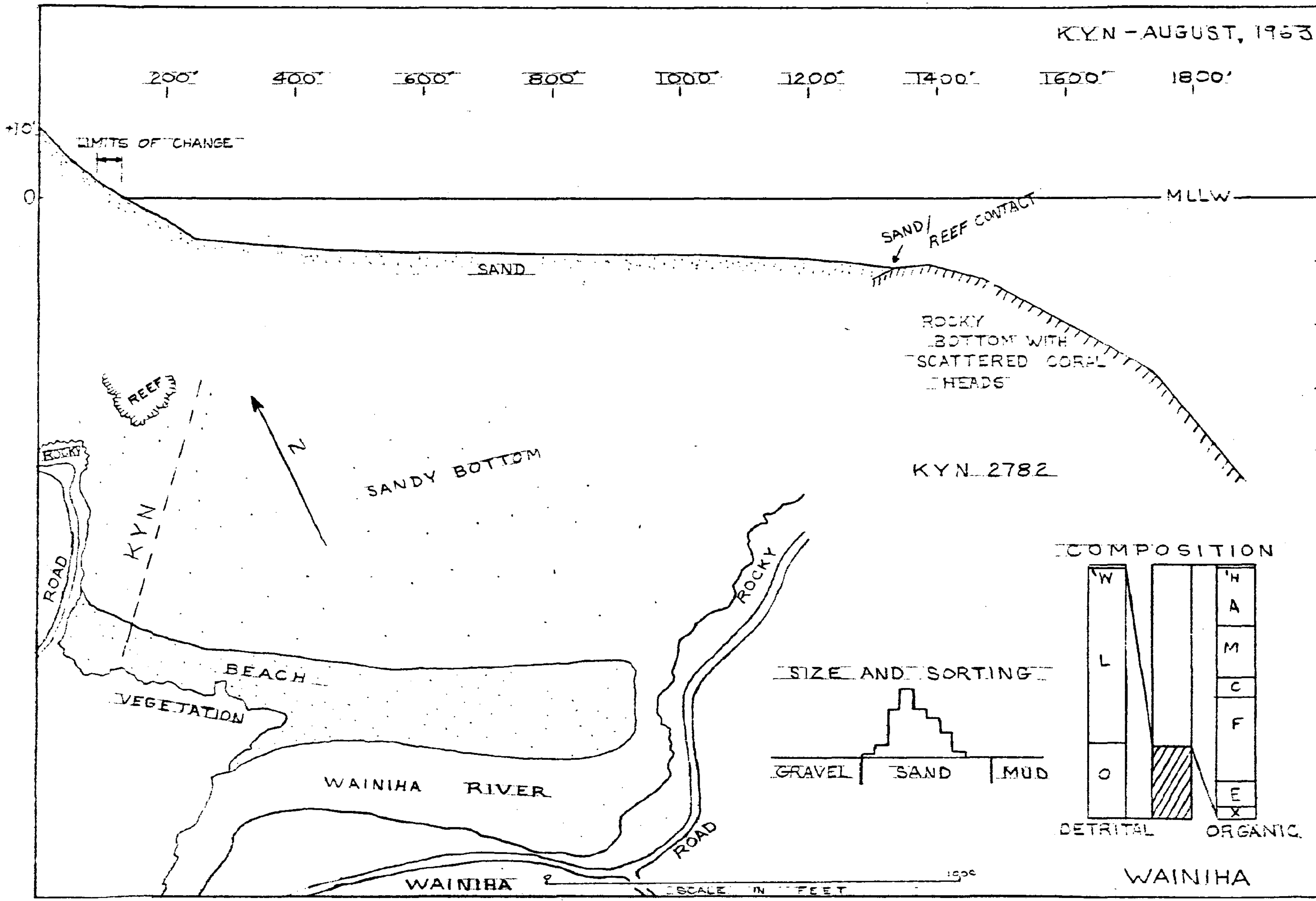

KYN - AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10'
0
LIMITS OF CHANGE
MLLW
SAND/ REEF CONTACT
SAND
-10'
-20'
-30'
-40'
ROCKY BOTTOM WITH SCATTERED CORAL HEADS
REEF
N
ROCKY
SANDY BOTTOM
KYN 2782
KYN
ROAD
ROCKY
COMPOSITION
W
L
O
H
A
M
C
F
E
X
DETRITAL
ORGANIC
BEACH
VEGETATION
SIZE AND SORTING
GRAVEL
SAND
MUD
WAINIHA RIVER
ROAD
WAINIHA
SCALE IN FEET
1500
WAINIHA

Fig. 10

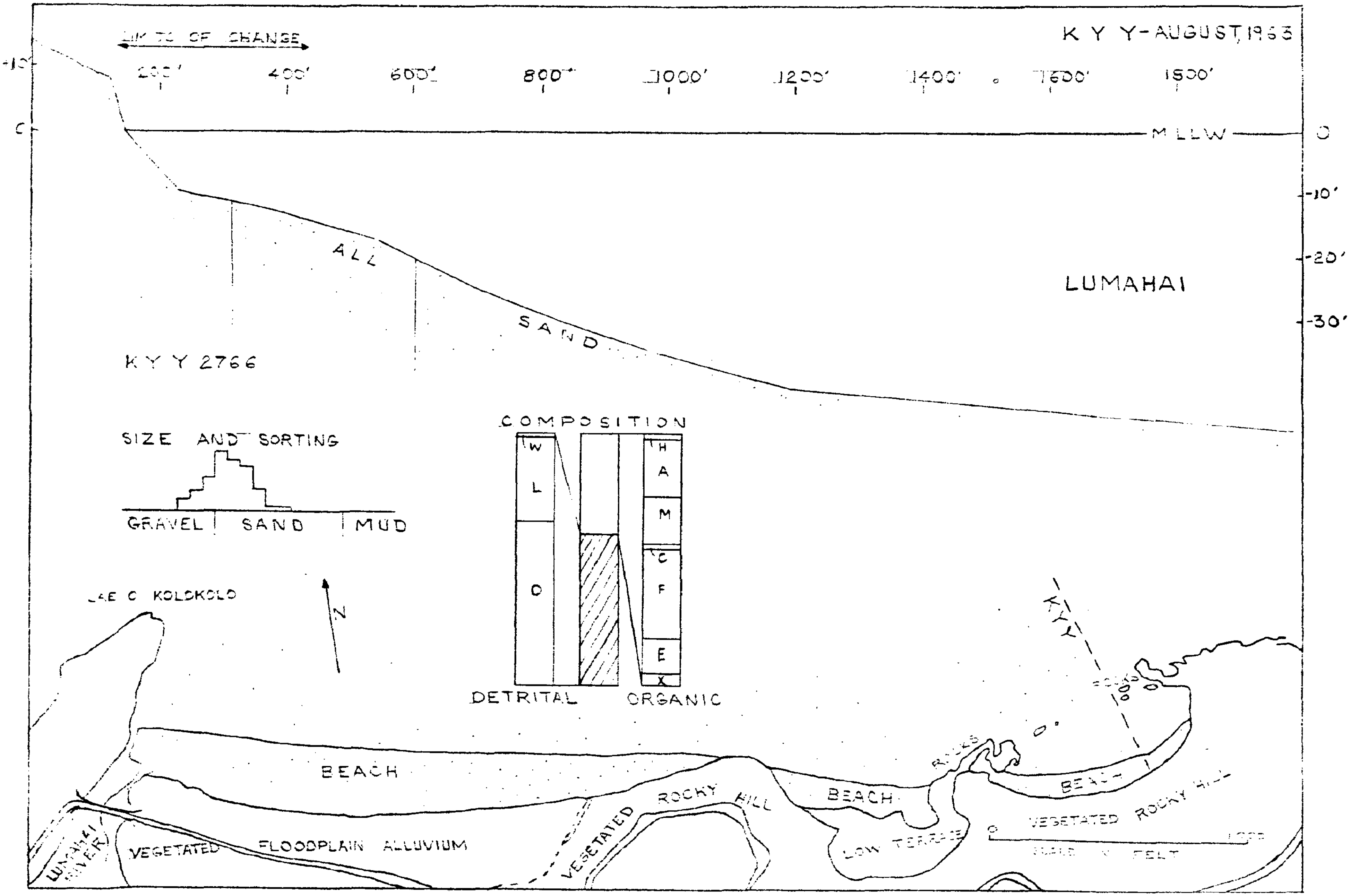
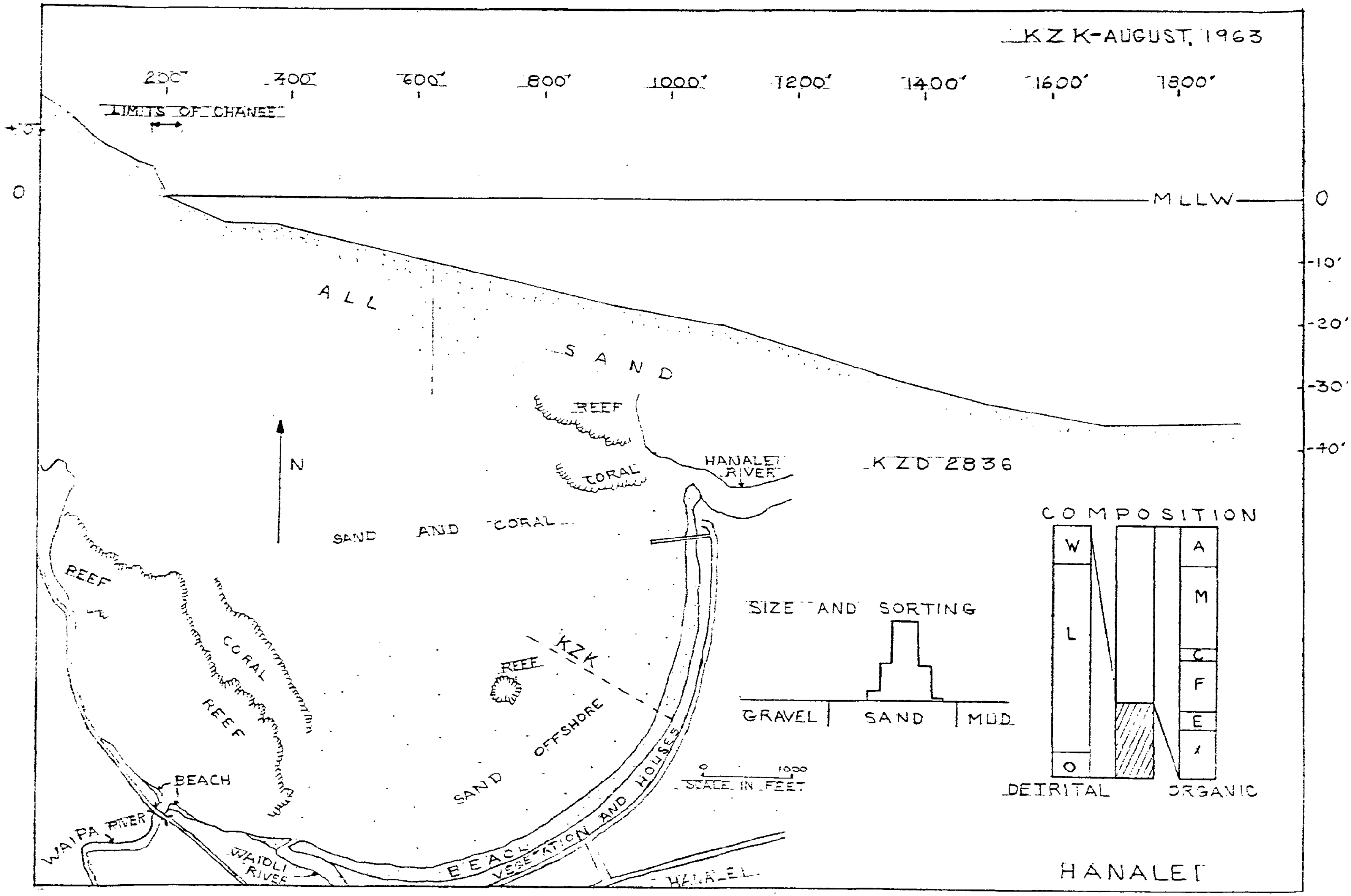

K Y Y-AUGUST, 1953
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10
0
MLLW
0
-10'
-20'
-30'
LUMAHAI
ALL
SAND
K Y Y 2766
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
H
A
M
C
F
E
X
DETRITAL
ORGANIC
N
KYY
BEACH
ROCKY HILL
BEACH
LOW TERRACE
VEGETATED ROCKY HILL
VEGETATED
FLOODPLAIN ALLUVIUM
VEGETATED
LUMAHAI RIVER

Fig. 11


KZK-AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
+10'
0
MLLW
0
-10'
-20'
-30'
-40'
ALL
SAND
REEF
CORAL
HANALEI RIVER
KZD 2836
N
SAND AND CORAL
REEF
CORAL
REEF
KZK
REEF
OFFSHORE
SAND
BEACH
WAIPA RIVER
WAIOLI RIVER
BEACH
VEGETATION AND HOUSES
HANALEI
SIZE AND SORTING
GRAVEL
SAND
MUD
0
1000
SCALE IN FEET
COMPOSITION
W
L
O
A
M
C
F
E
DETRITAL
ORGANIC
HANALEI
Fig. 12

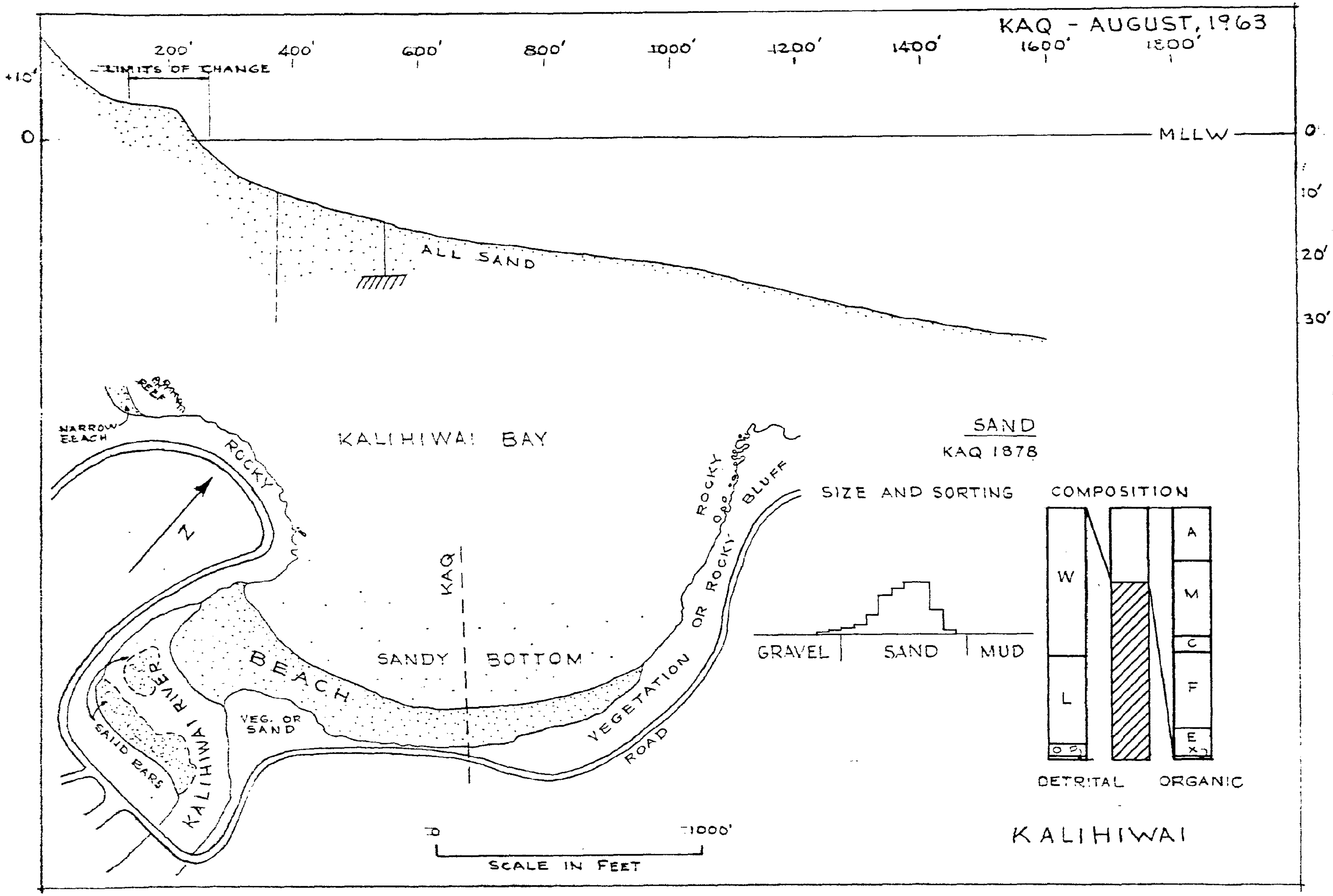

KAQ - AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
+10'
0
MLLW
0'
10'
20'
30'
ALL SAND
NARROW BEACH
REEF
ROCKY
KALIHIWAI BAY
N
KAQ
SANDY BOTTOM
BEACH
VEG. OR SAND
KALIHIWAI RIVER
SAND BARS
ROCKY
BLUFF
VEGETATION OR ROCKY
ROAD
0
1000'
SCALE IN FEET
SAND
KAQ 1878
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
A
M
C
F
E
X
DETRITAL
ORGANIC
KALIHIWAI

Fig. 13

the winter and coming back in during the summer. Kalihiwai beach generally has a low slope with at least one berm that is often cusped.

Beach sand is medium-to-coarse-grained, and is largely detrital, supplied by Kalihiwai River.

Kalihiwai is a poor swimming beach, as the water is often murky, and during periods of high waves there is a strong longshore current to the east.

Moloaa K-6. (Figure 14.) Moloaa Beach is a 1/4-mile-long, slightly arcuate bay-head barrier beach. The beach is of approximate equal width along its entire length, and the width varied but little during 1962 and 1963. The foreshore has a low slope that is broken in places by outcrops of beachrock. Apparently Moloaa Stream supplies only small quantities of sand-sized detritus, as the beach sand is predominantly calcareous.

Behind the beach are low dunes vegetated with grass and ironwood trees. There is a long beachrock outcrop in the surf zone, but seaward of the outcropping the bottom is largely sand. The water commonly is murky because of fine-grained sediment from Moloaa Stream.

Anahola K-6. (Figure 15.) Anahola Beach is an arcuate beach about 1-1/2 miles long, that is 170 to 220 feet in width opposite the center of Anahola Bay, but narrows to about 100 feet in width at both ends.

The beach is at the mouth of Anahola Valley and Anahola Stream crosses the beach just north of the middle. During the period of the study, the perennial stream changed the position of its mouth by about 500 feet along the beach.

The beach generally has a low slope and at least one berm. Only once were cusps seen that had cut into the berm. This beach appears to erode slightly during the summer and to build out during the winter. However, our measurements of the amount of beach change are poor, because the stream mouth migrated across our survey range during the latter part of the study.

Beach sand at Anahola is predominantly calcareous, and of medium-grain size. The offshore area is largely sand, and there are low sandy dunes behind part of the beach.

Kealia K-6. (Figure 16.) Kealia Beach is a 1/2-mile-long by 150-foot-wide beach at Kealia, Kauai. The beach is held on the south by a rocky point and on the north by a small jetty. Kapaa Stream crosses the beach at the south end. The width of this beach showed little variation except for some small loss during the winter. The sand is highly calcareous.

Behind Kealia Beach are low dunes, a cane-hauling road, and the main highway. The remnants of a small sand-mining operation were seen at the north end of the beach. The moderate alongshore current apparently is to the north even when waves approach from the northeast.

Kapaa K-6. (Figure 17.) Kapaa Beach is a 3/4-mile-long beach held at both ends by jettys built to prevent meandering of the mouths of canals that drain the swamps back of the town of Kapaa. The beach has a uniform width of about 50 feet. A 20-foot loss to erosion was noted after a severe kona storm in January 1963. From a low scarp cut at the back of the beach, the foreshore slopes directly to the waterline. There is no berm and cusps were never noticed here.

The predominantly calcareous sand is supplied by the extensive

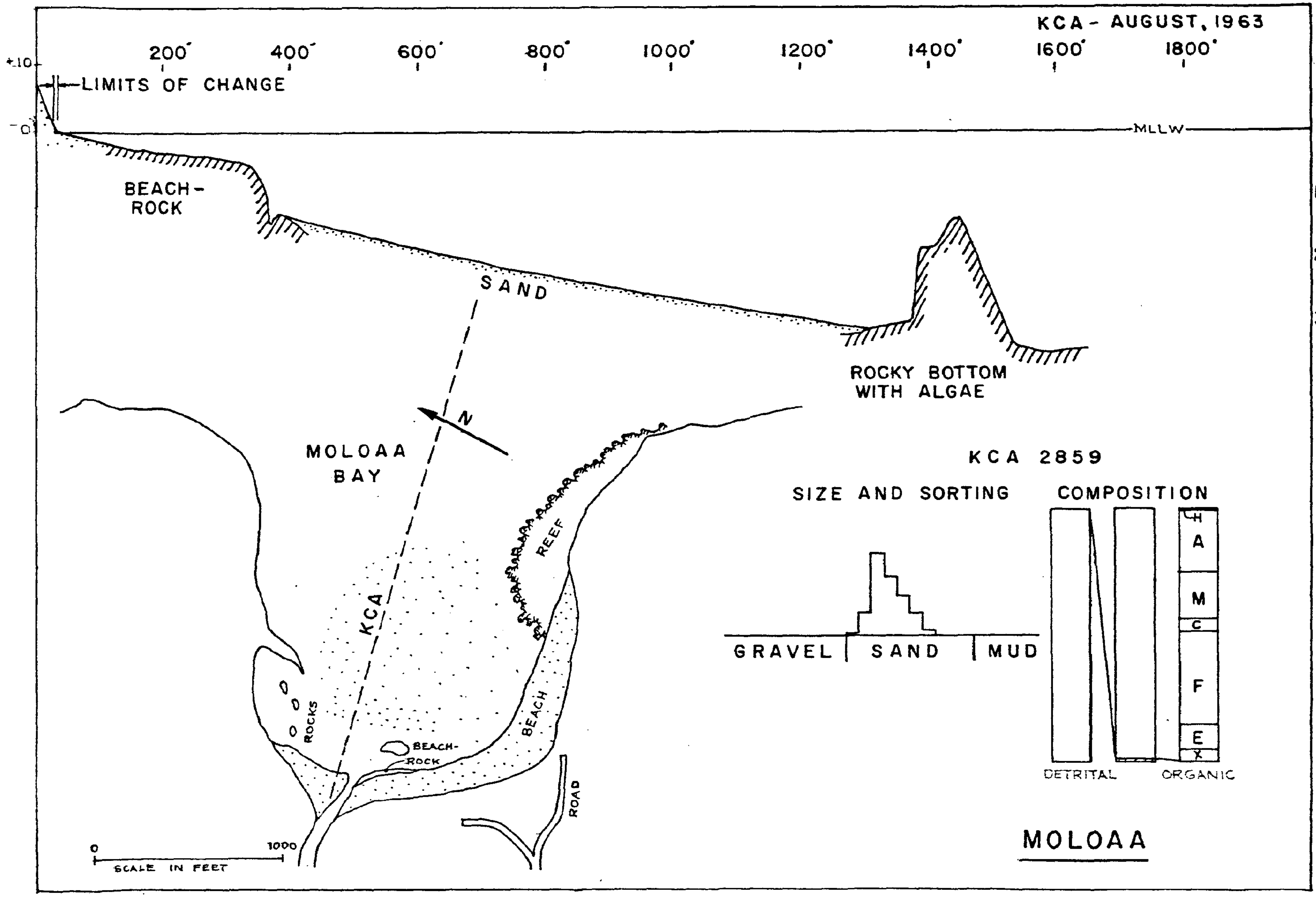

KCA - AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10
-0
LIMITS OF CHANGE
MLLW
0'
10'
20'
30'
BEACH-ROCK
SAND
ROCKY BOTTOM WITH ALGAE
N
MOLOAA BAY
KCA
REEF
ROCKS
BEACH-ROCK
BEACH
ROAD
0
1000
SCALE IN FEET
KCA 2859
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
H
A
M
C
F
E
X
DETRITAL
ORGANIC
MOLOAA

Fig. 14

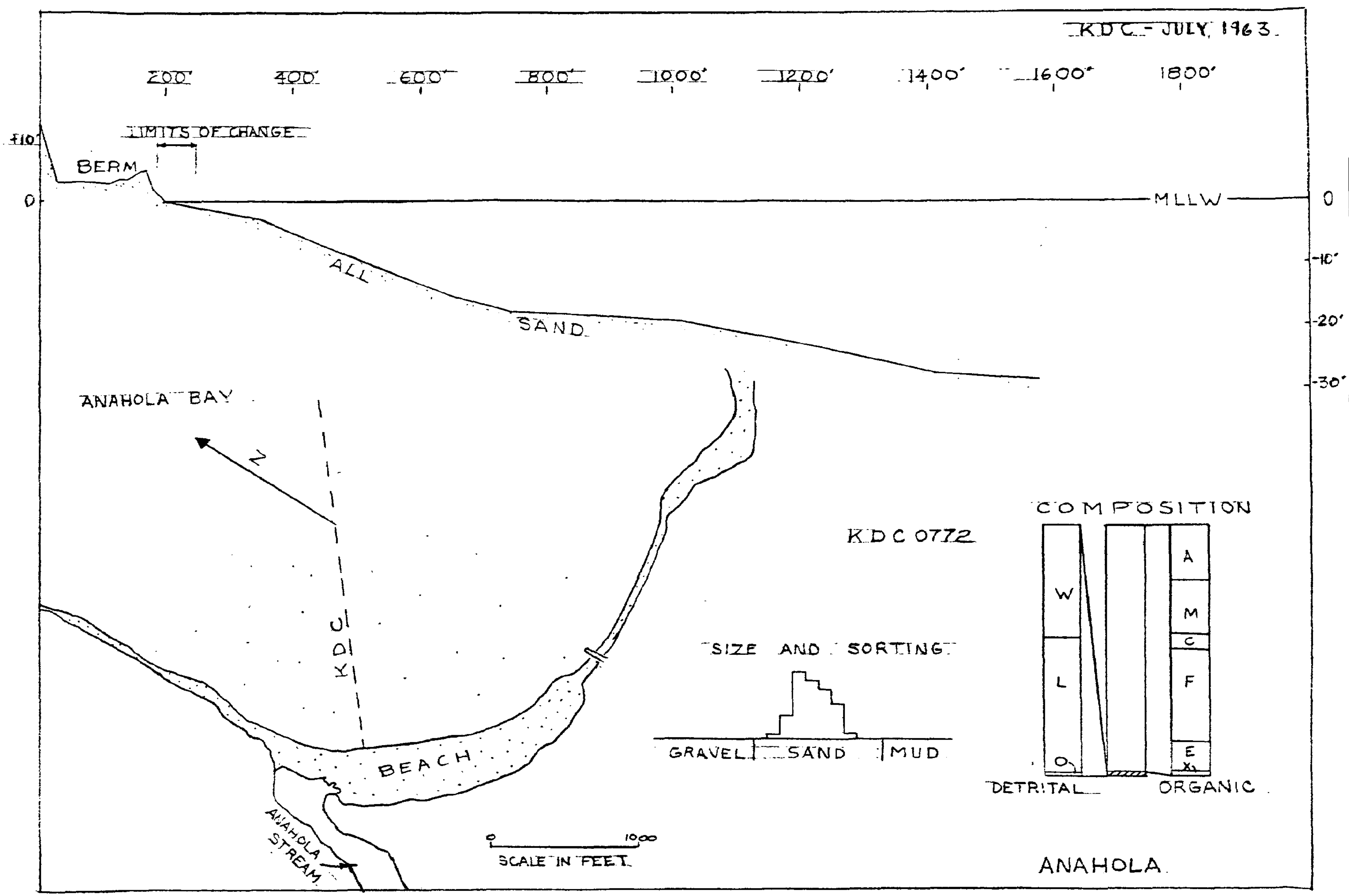

KDC - JULY, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
+10'
BERM
0
MLLW
0
-10'
-20'
-30'
ALL
SAND
ANAHOLA BAY
N
KDC
BEACH
ANAHOLA STREAM
KDC 0772
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
A
M
C
F
E
X
DETRITAL
ORGANIC
0
1000
SCALE IN FEET
ANAHOLA

Fig. 15

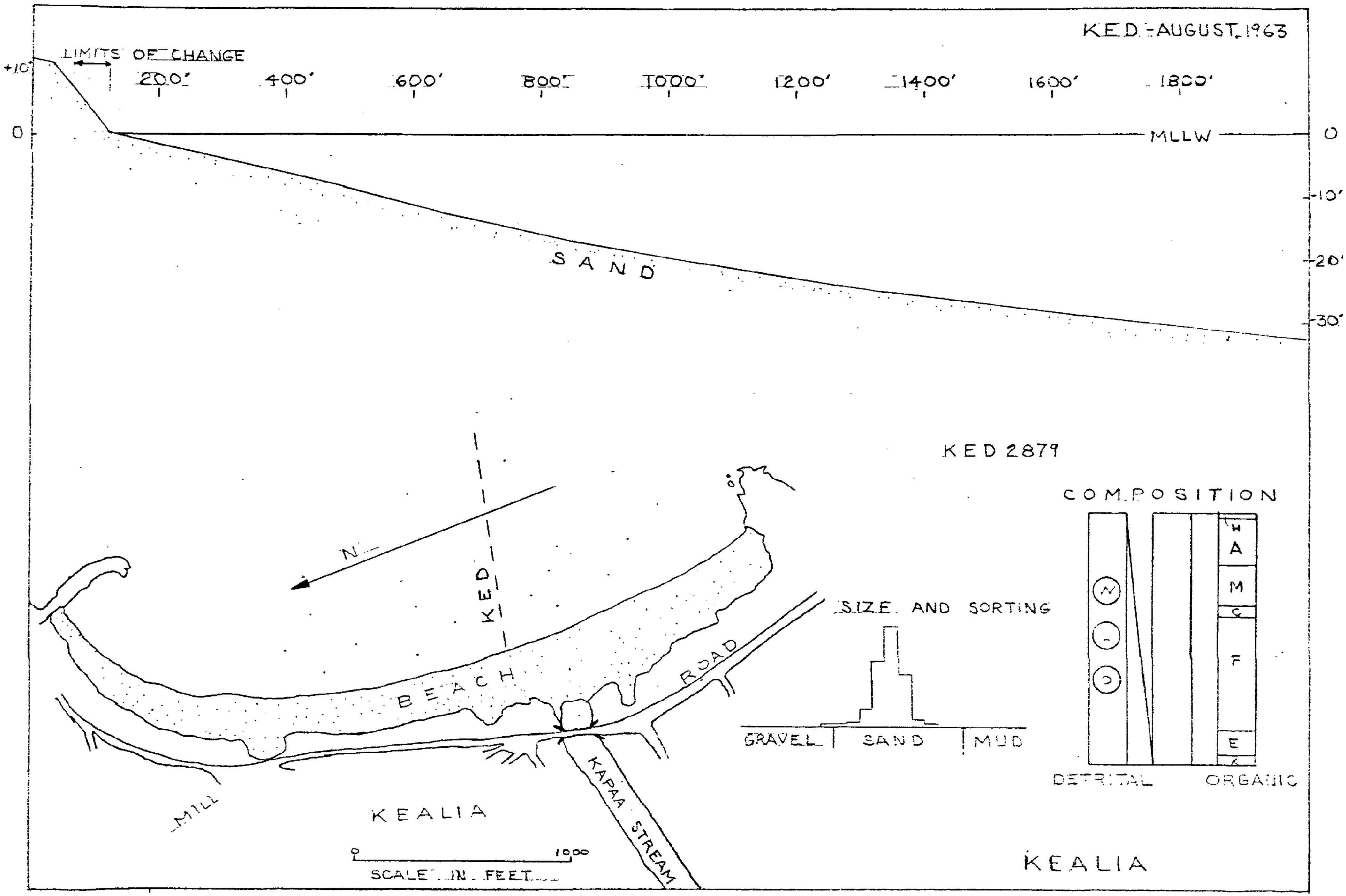
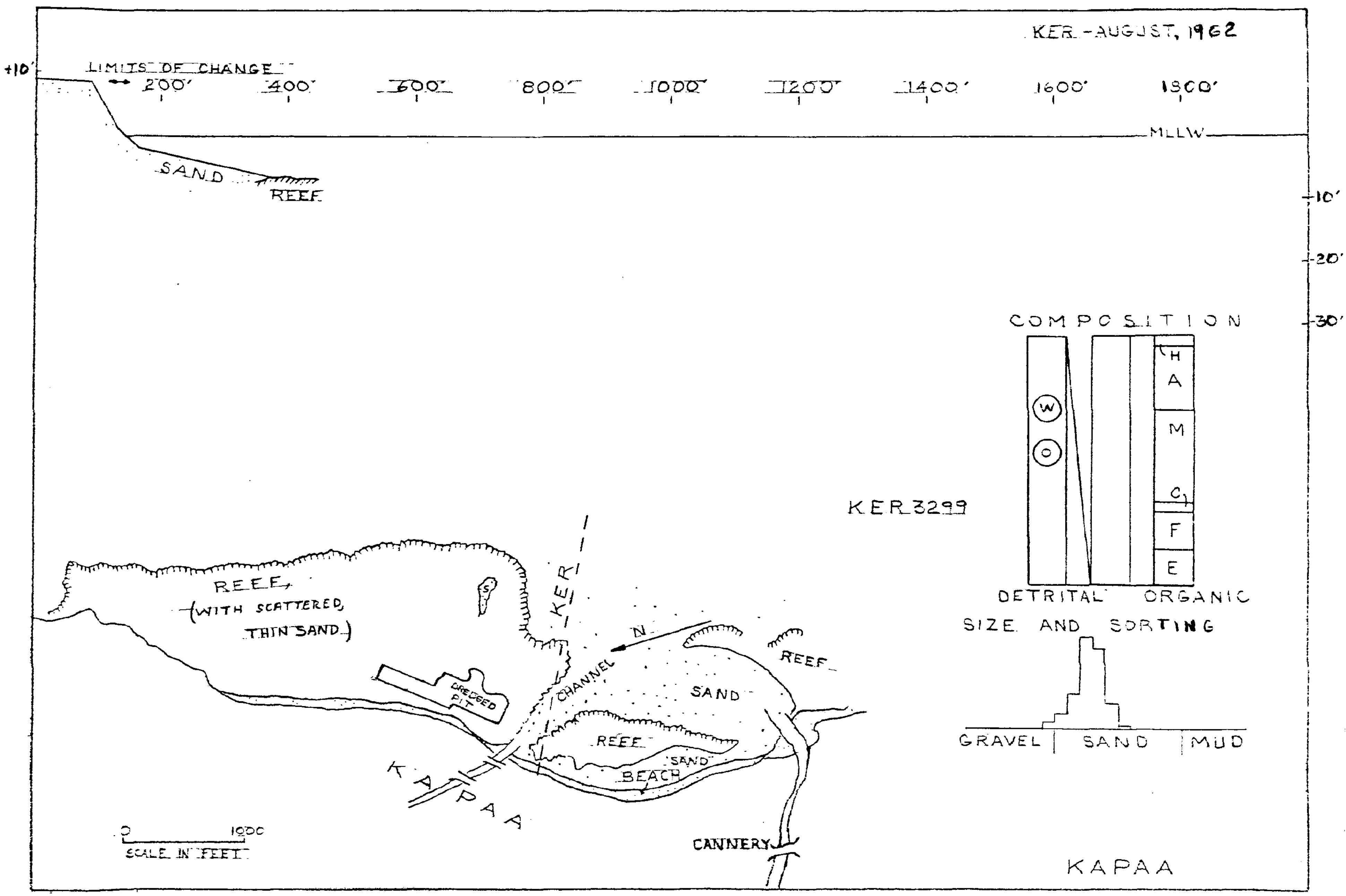

KED - AUGUST 1963
LIMITS OF CHANGE
+10'
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
-10'
-20'
-30'
SAND
KED 2879
COMPOSITION
H
A
M
F
E
DETRITAL
ORGANIC
SIZE AND SORTING
GRAVEL
SAND
MUD
N
KED
BEACH
ROAD
KAPAA STREAM
MILL
KEALIA
0
1000
SCALE IN FEET
KEALIA

Fig. 16



KER - AUGUST, 1962
+10'
LIMITS OF CHANGE
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
SAND
REEF
-10'
-20'
-30'
COMPOSITION
W
O
H
A
M
C
F
E
DETRITAL
ORGANIC
KER 3299
SIZE AND SORTING
GRAVEL
SAND
MUD
REEF
(WITH SCATTERED, THIN SAND)
S
KER
N
CHANNEL
SAND
REEF
DREDGED PIT
REEF
SAND
BEACH
KAPAA
0
1000
SCALE IN FEET
CANNERY
KAPAA

Fig. 17

reef. Beaches both north and south of this segment of coast are decidedly narrower and are being eroded more actively.

This is not a beach good for swimming, because the water is shallow and the bottom is rocky immediately offshore. Off the mouth of the canal at the northern end of the beach there is a strong current flowing seaward that can be very dangerous.

Additional comments about Kapaa are in the section on special studies.

Wailua K-6. (Figure 18.) At the mouth of Wailua River is a slightly arcuate beach about 1/2-mile long. The beach was about 100 feet wide when first measured in May 1962, and varied only about 25 feet until April 15, 1963. At that time a flood of the Wailua River caused severe erosion of the south end of the beach, and the sand was cut back into the vegetated back beach area. By August 1963 a narrow back beach zone with an erosional scarp and a narrow foreshore had returned. Prior to the flood the beach had a fairly steep foreslope with a fairly high berm that sometimes was marked with cusps.

The north end of the beach is more stable, but is not used as extensively as the south end, which is immediately adjacent to the entrance of a large resort.

The offshore area is mainly sand, with some bars that may be buried beachrock or perhaps giant ripples.

Oahu: by J. F. Campbell and R. Moberly, Jr.

Sandy Beach O-1. (Figure 19.) Sandy Beach is a 1200-foot-long, slightly arcuate beach between a lava point at the northern end and a terraced sea cliff of tuff at the southern end. This beach is quite steep and is often cusped. It is part of Sandy Beach Park, mainly an area of low dunes covered by grass and kiawe trees.

The sand at this beach is medium-sized and well sorted, and is composed predominantly of calcareous grains.

The deepest area close to shore trends south along the edge of the sea cliff, and has a sandy bottom. Most of the offshore area is a mixture of patches of sand, lava, and reef.

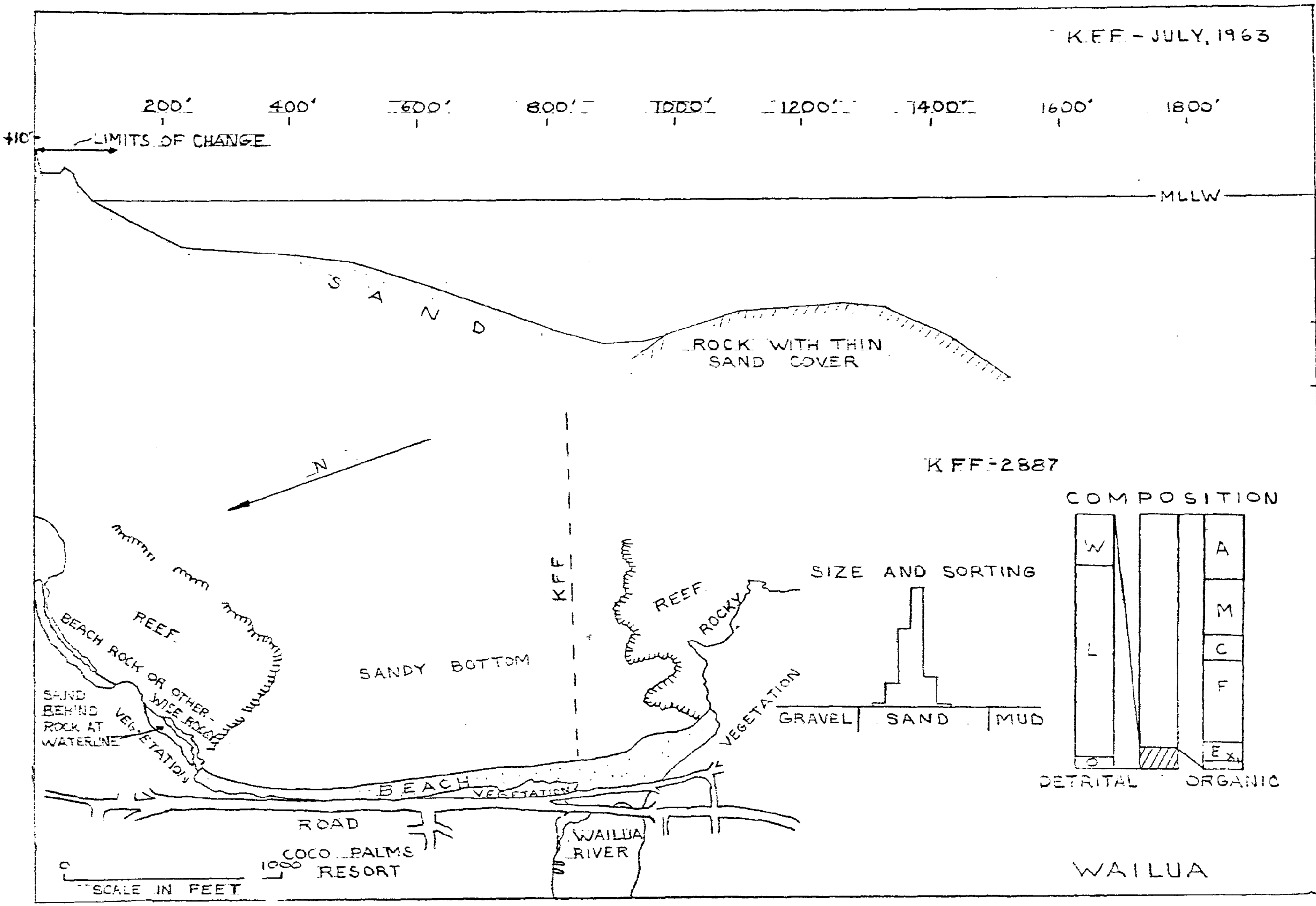
Although it is a popular body-surfing and sunbathing beach, there are dangerous rip currents when the surf is strong.

Comments on sand sampling at Sandy Beach are in a later section of this report.

Hanauma Bay O-1. (Figure 20.) Hanauma Beach is a 2000-foot-long bay head beach in a pair of breached volcanic craters. The beach ranges in width from about 30 to 100 feet. Off the beach is a shallow fringing reef with large sand pockets in it. This makes ideal swimming conditions, for the wave energy is expended on the outer edge of the reef leaving the sand pockets calm. Outside the reef edge large coral heads and strong currents make swimming dangerous.

The beach is surrounded by the cliffs of the craters, but is accessible by a trail from the parking lot at the top of the cliff. A wave-cut terrace a few feet above sea level extends along the northern, and part of the southern bay shores. It is a popular place with fishermen except when waves are high making it extremely dangerous.

The composition of the sand varies greatly from place to place. Near the waterline selective sorting by the gentle waves leave some streaks of sand that are composed predominantly of olivine grains.



KFF - JULY, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10'
LIMITS OF CHANGE
MLLW
-10'
-20'
-30'
SAND
ROCK WITH THIN SAND COVER
N
KFF
KFF-2887
COMPOSITION
W
L
O
A
M
C
F
Ex
DETRITAL
ORGANIC
SIZE AND SORTING
GRAVEL
SAND
MUD
REEF
ROCKY
REEF
SANDY BOTTOM
BEACH ROCK OR OTHERWISE ROCKY
SAND BEHIND ROCK AT WATERLINE
VEGETATION
BEACH
VEGETATION
VEGETATION
ROAD
WAILUA RIVER
COCO PALMS RESORT
0
1000
SCALE IN FEET
WAILUA

Fig. 18

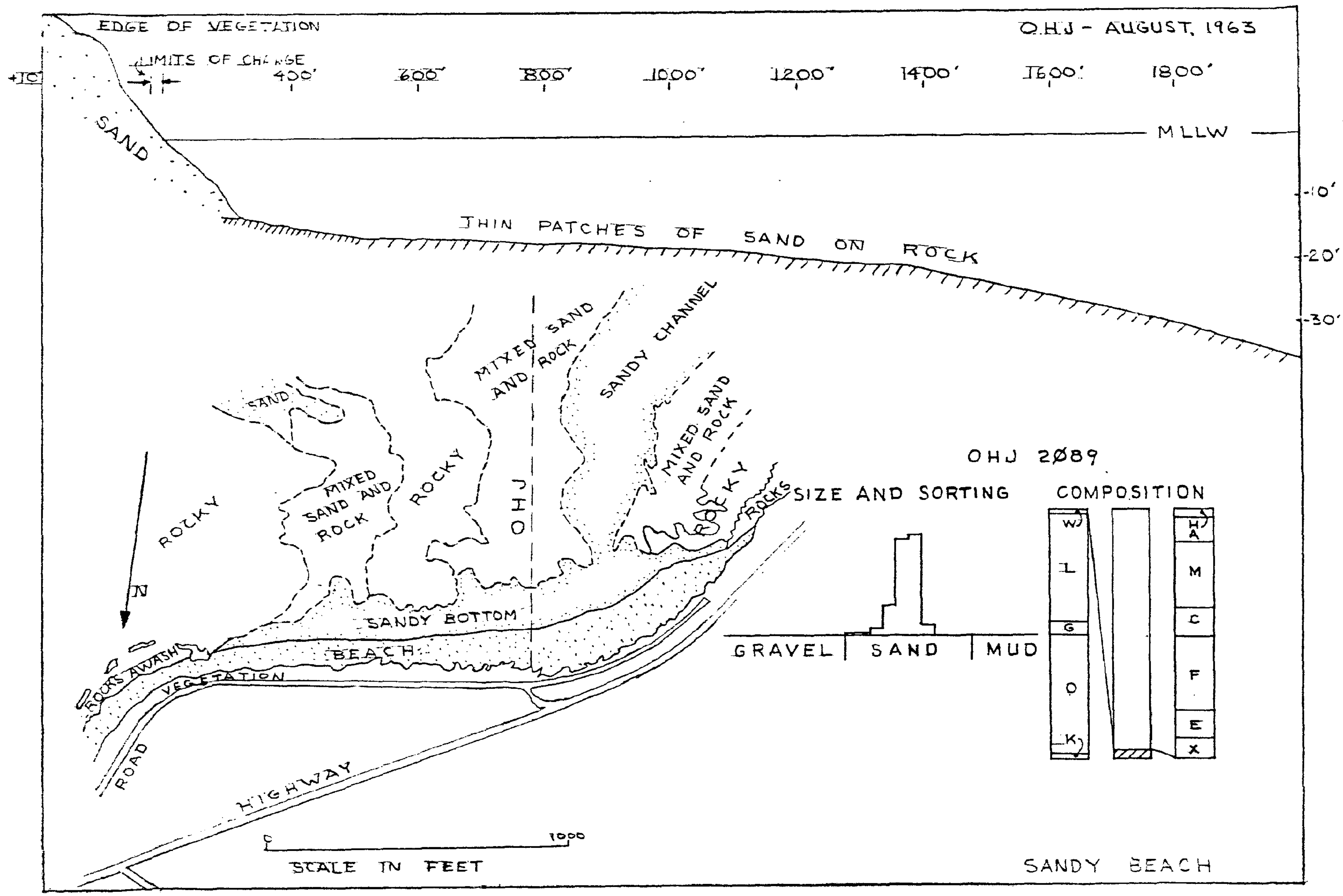

EDGE OF VEGETATION
O.H.J - AUGUST, 1963
LIMITS OF CHANGE
+10
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
SAND
MLLW
-10'
-20'
-30'
THIN PATCHES OF SAND ON ROCK
SAND
MIXED SAND AND ROCK
ROCKY
MIXED SAND AND ROCK
SANDY CHANNEL
MIXED SAND AND ROCK
ROCKY
ROCKS
OHJ
ROCKY
N
SANDY BOTTOM
BEACH
ROCKS AWASH
VEGETATION
ROAD
HIGHWAY
0
1000
SCALE IN FEET
OHJ 2089
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
O
K
H
A
M
C
F
E
X
SANDY BEACH

Fig. 19

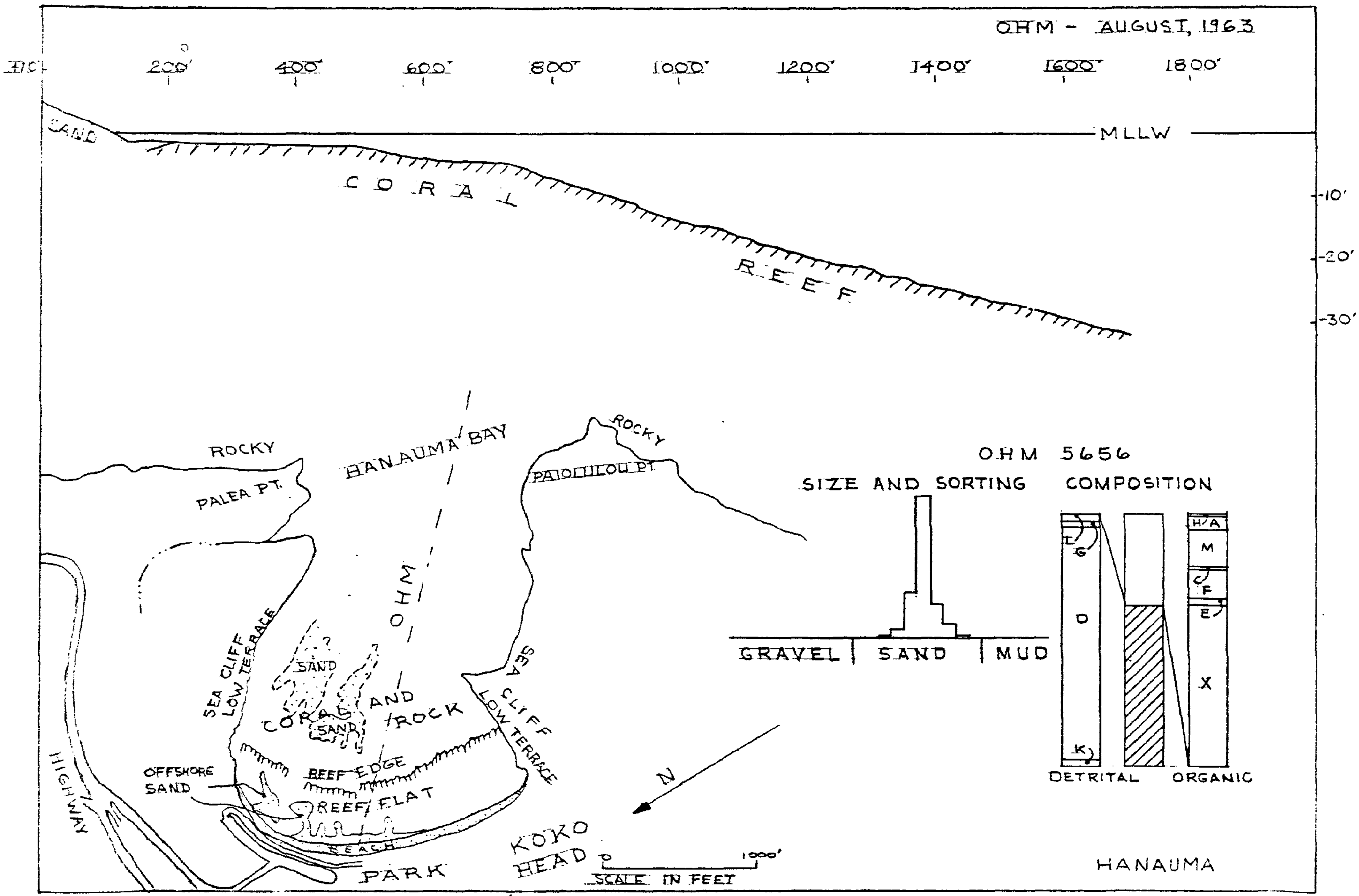

OHM - AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
SAND
MLLW
CORAL
REEF
-10'
-20'
-30'
ROCKY
PALEA PT.
HANAUMA BAY
ROCKY
PAIOLUOLU PT
OHM
SEA CLIFF
LOW TERRACE
SAND
CORAL AND ROCK
SAND
OFFSHORE
SAND
REEF EDGE
REEF FLAT
BEACH
HIGHWAY
PARK
KOKO HEAD
N
0
1000'
SCALE IN FEET
OHM 5656
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
G
D
K
H/A
M
C
F
E
X
DETRITAL
ORGANIC
HANAUMA

Fig. 20

Kahala O-1. (Figure 21.) Kahala is a long, narrow, relatively straight beach extending from a jetty on the east to Black Point on the west. The beach varied in width from 20 to 30 feet, and showed a maximum horizontal change of 10 feet during the period of study. A wide and shallow fringing reef protects the beach from all but gentle waves, the calcareous sand is fairly coarse and is very poorly sorted.

When this beach was last visited in August 1963, the length of the breakwater was being extended and the beach east and west of it was being disturbed by construction equipment.

Because of the shallowness of the fringing reef there are no good swimming areas along this beach, although there are a few sand pockets where people do swim and wade. A sand-bottomed channel crosses the reef.

Comments on the reef-dwelling organisms at Waialae-Kahala are in a separate section of this report.

Waikiki O-2. (Figure 22.) Waikiki Beach originally was a barrier beach between the Ala Wai-Moiliili duckponds and swamps and the ocean. In recent years it has become an artificial beach, nourished by bringing in sand. A typical artificial section is Kuhio Beach, near the center of Waikiki. This is a triangular-shaped beach about 300 feet long, and its greatest width is 100 feet, at the groin bounding its west end. During the last year of this study, Kuhio Beach varied in width by about 15 feet. It is not known whether sand was added to the beach during the period or not. This is part of a small public park and is a good beach for swimming. There is a submerged sea wall about 200 feet offshore that might be a hazard to poorly-observant swimmers.

South of Kuhio Beach the width of Waikiki Beach seems to depend on the presence or absence of groins. Sand normally is added to the south sides of groins, indicating that the alongshore drift is from the south. The reef edge is fairly distinct off this section of beach, with two narrow sand-bottomed channels crossing the reef.

The center area of reef off Kuhio Beach and the adjacent hotels has been largely cleared of coral heads for the convenience of swimmers. Sand lies in large patches that seem to shift their positions very little, according to older air photographs. West of the groin at the west edge of the Royal Hawaiian Hotel the beach is very narrow, if it is present at all. The reef offshore has few sandy areas, but a moderately large channel filled with sand to a thickness greater than 20 feet does cross the reef offshore from the Halekulani Hotel.

Ewa Beach O-3. (Figure 23.) Ewa Beach is a straight beach west of the entrance to Pearl Harbor. The area most closely studied is at Puulua Beach Park. There the beach is slightly less than 100 feet wide and varies in width over the period of the study by about 20 feet. The foreshore is usually quite steep and sometimes there is a berm of gravel built in storms. The sand here is medium-to-coarse-grained, poorly sorted, and predominantly calcareous.

West of the beach park, where the houses of Ewa Beach are built along the old, low dune ridge, the beach tapers in width and part of the shoreline is sea wall. Swimming is poor here because rocks are exposed in shallow water immediately off the beach at a number of places, and oftentimes the water is dirty.

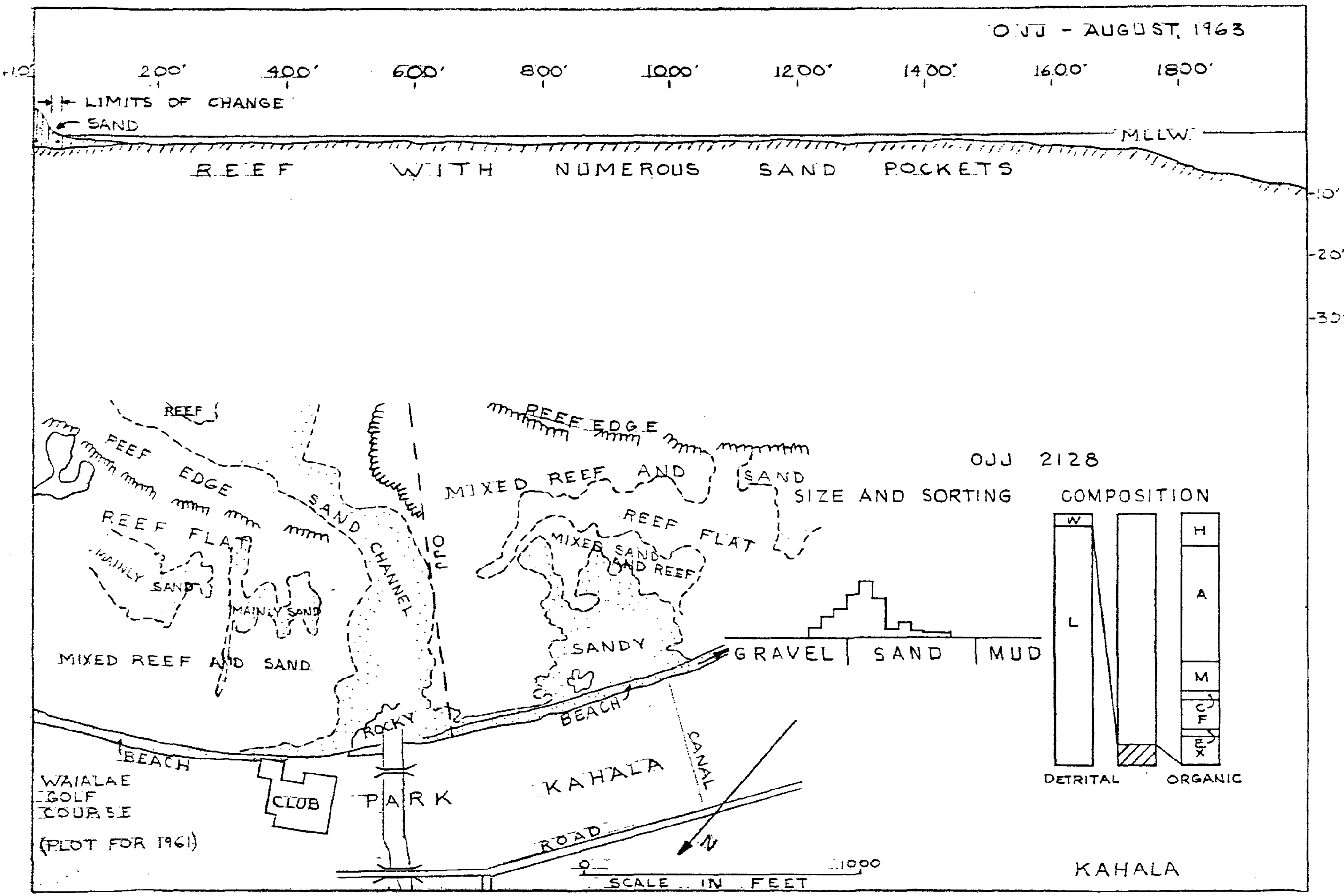
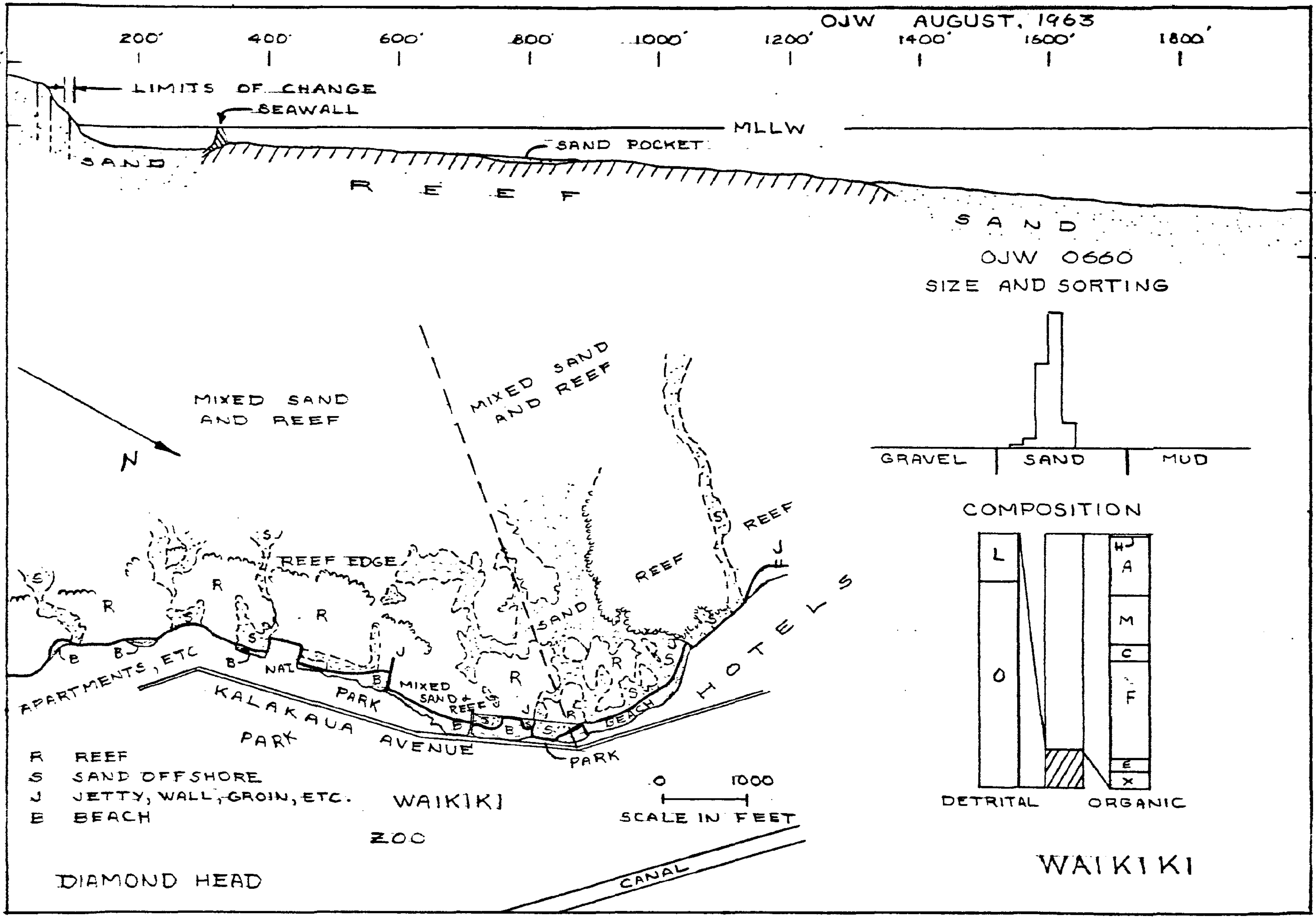

OJJ - AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10'
-10'
-20'
-30'
LIMITS OF CHANGE
SAND
MLLW
REEF WITH NUMEROUS SAND POCKETS
REEF
REEF EDGE
REEF FLAT
MAINLY SAND
MAINLY SAND
MIXED REEF AND SAND
SAND CHANNEL
OJJ
REEF EDGE
MIXED REEF AND SAND
REEF FLAT
MIXED SAND AND REEF
SANDY
BEACH
ROCKY
BEACH
WAIALAE GOLF COURSE
(PLOT FOR 1961)
CLUB
PARK
KAHALA
CANAL
ROAD
N
0
1000
SCALE IN FEET
OJJ 2128
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
H
A
M
C
F
E
X
DETRITAL
ORGANIC
KAHALA

Fig. 21



OJW AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10'
0
-10'
-20'
LIMITS OF CHANGE
SEAWALL
MLLW
SAND POCKET
SAND
REEF
SAND
OJW 0660
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
L
O
HJ
A
M
C
F
E
X
DETRITAL
ORGANIC
WAIKIKI
MIXED SAND AND REEF
MIXED SAND AND REEF
N
REEF EDGE
REEF
REEF
SAND
MIXED SAND + REEF
HOTELS
BEACH
PARK
NAT
APARTMENTS, ETC
KALAKAUA AVENUE
PARK
R REEF
S SAND OFFSHORE
J JETTY, WALL, GROIN, ETC.
E BEACH
WAIKIKI
ZOO
0
1000
SCALE IN FEET
CANAL
DIAMOND HEAD

Fig. 22

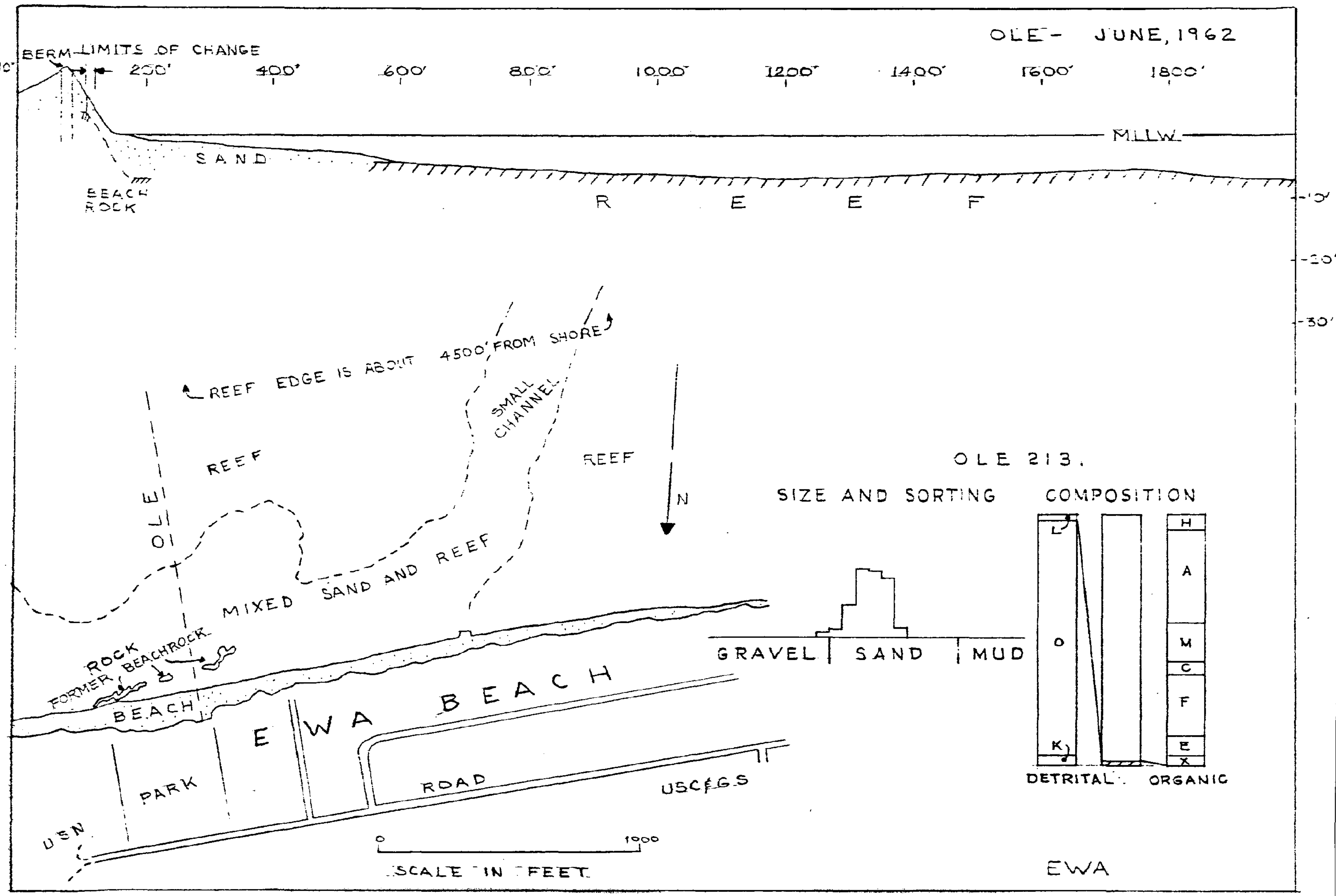

OLE - JUNE, 1962
BERM
LIMITS OF CHANGE
+10'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
SAND
BEACH ROCK
R E E F
-10'
-20'
-30'
REEF EDGE IS ABOUT 4500' FROM SHORE
SMALL CHANNEL
REEF
REEF
N
OLE
MIXED SAND AND REEF
ROCK
FORMER BEACHROCK
BEACH
EWA BEACH
PARK
ROAD
USC&GS
USN
0
1000
SCALE IN FEET
OLE 213.
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
L
O
K
H
A
M
C
F
E
X
DETRITAL
ORGANIC
EWA

Fig. 23

The reef off Ewa Beach is wide and irregular in both topography and distribution of sandy sediment.

Oneula Beach O-3. (Figure 24.) Oneula Beach extends from the raised coral-reef shoreline at the Papipi Road end of Ewa Beach westward nearly 3000 feet to a broad, low rocky point.

The narrow beach lies between the Ewa Plain, a raised Pleistocene coral reef, and the present-day reef that fringes southern Oahu. Oneula Beach generally has a level backshore that is built to a sharp berm crest and then to a steep foreshore.

Sand from this beach is almost entirely calcareous, moderately well sorted, and of medium-grain-size. Short lengths of low beach ridges of calcareous gravel occur along the beach.

The wide expanse of predominantly sandy bottom on the reef off the middle of the beach is only slightly below the level of the adjacent reef flat, but about ½ mile offshore a channel-shape is more distinct. However, the channel is nowhere as pronounced as the channels on the north and east coasts of Oahu.

Nanakuli O-4. (Figure 25.) The beach near Nanakuli with easy access is at Kalanianaole Beach Park. This is a pocket beach about 500 feet long by 125 feet wide; the width varied as much as 50 feet during the period of the study and was widest during the summer months. Cusps and berms were usually present. The beach has a steep foreshore and thus the uprush zone is very dangerous when large waves are breaking. However, when waves are low this is a good swimming beach.

The sand is medium to coarse in size and fairly well sorted. Over 90% of the grains are of calcareous materials.

A sand-bottomed channel across the reef slope lies off the present-day barred mouth of Nanakuli Stream.

Maile 0-4. (Figure 26.) Maile is a fairly long, wide beach that is broken into three segments by two areas of beachwork development. During this investigation the northern segment varied in width by about 75 feet, with sand being eroded during the winter and being returned to the beach in the late spring and early summer.

The beach is held on the northwest end by the wall of a canal built to contain Mailiilii Stream during flash floods. Some sand blows over the wall into the drainage canal. The foreshore slope varies from fairly steep in winter to rather flat in summer. When the beach is wide, there is often a berm on it, but when it is narrow it slopes down to the shoreline from an erosional escarpment cut in the low dune back of the beach. The sand is medium sized and fairly well sorted with only a negligible amount of detrital material.

Offshore, the bottom is a dead reef-flat with water deep enough to allow swimming. However, when high waves create much surf, there are dangerous rip currents.

Pokai Bay 0-5. (Figure 27.) Pokai Bay Beach is an arcuate pocket beach partly inside the breakwater that protects the Pokai small boat harbor. The beach varies in width from 225 feet to about 30 feet, being narrow only for a short section near the boat ramp at the southeast end of the beach. The beach is very flat and generally has no berm.

There is an alongshore drift of sand toward the southeast that buries the boat ramp on occasion. A new boat ramp has been built and

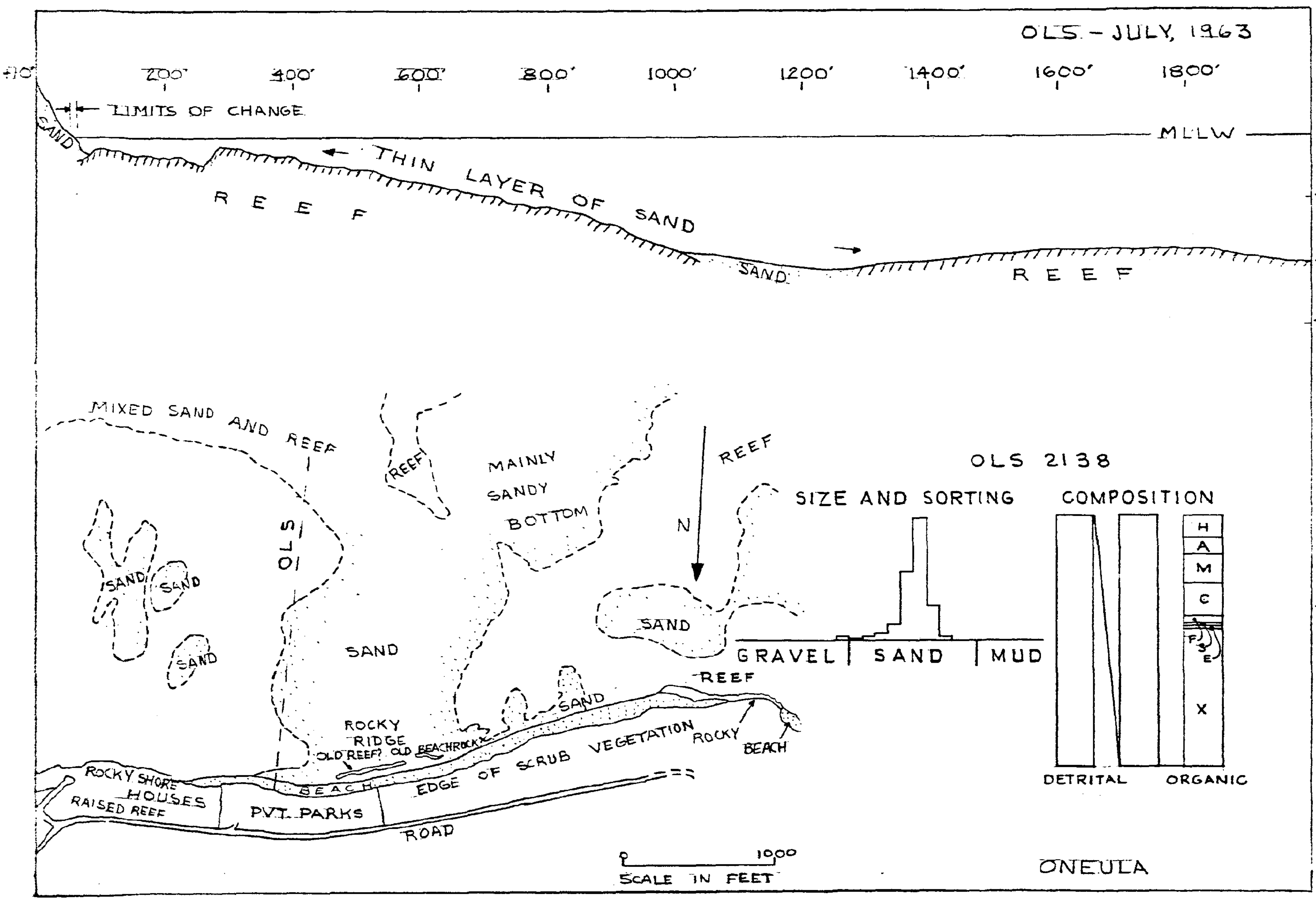

OLS - JULY, 1963
+10'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
MLLW
-10'
-20'
-30'
SAND
THIN LAYER OF SAND
REEF
SAND
REEF
MIXED SAND AND REEF
OLS
REEF
MAINLY SANDY BOTTOM
N
REEF
SAND
SAND
SAND
SAND
SAND
SAND
ROCKY RIDGE
OLD REEF? OLD BEACHROCK
ROCKY SHORE
HOUSES
RAISED REEF
BEACH
PVT. PARKS
EDGE OF SCRUB VEGETATION
ROAD
REEF
ROCKY
BEACH
OLS 2138
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
H
A
M
C
F
S
E
X
DETRITAL
ORGANIC
0
1000
SCALE IN FEET
ONEULA

Fig. 24

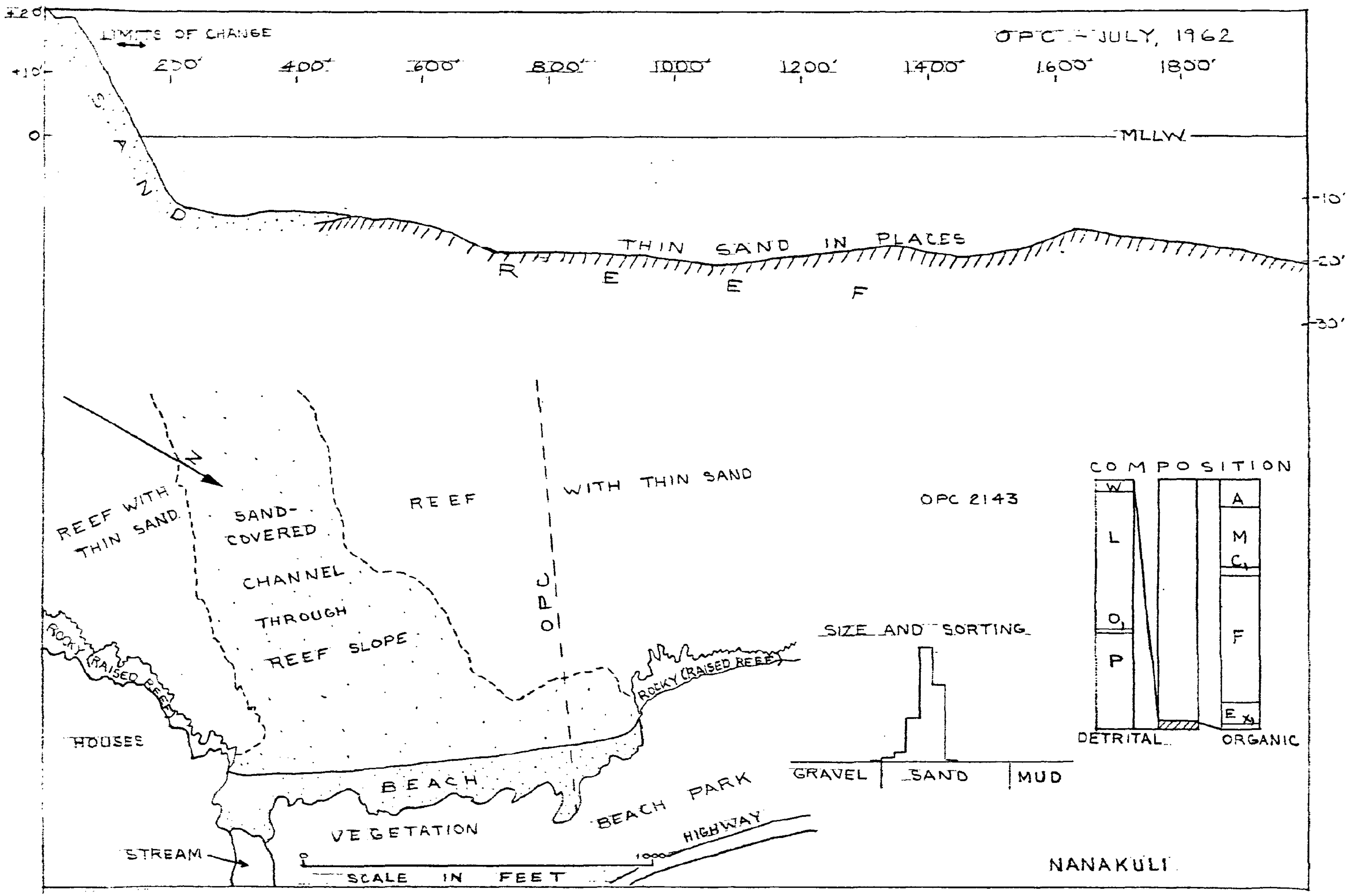

OPC - JULY, 1962
LIMITS OF CHANGE
+20'
+10'
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
-10'
-20'
-30'
SAND
THIN SAND IN PLACES
REEF
N
REEF WITH THIN SAND
SAND-COVERED CHANNEL THROUGH REEF SLOPE
REEF
WITH THIN SAND
OPC
OPC 2143
COMPOSITION
W
L
O
P
A
M
C
F
E
X
DETRITAL
ORGANIC
SIZE AND SORTING
GRAVEL
SAND
MUD
ROCKY (RAISED REEF)
ROCKY (RAISED REEF)
HOUSES
BEACH
BEACH PARK
HIGHWAY
VEGETATION
STREAM
0
1000
SCALE IN FEET
NANAKULI

Fig. 25

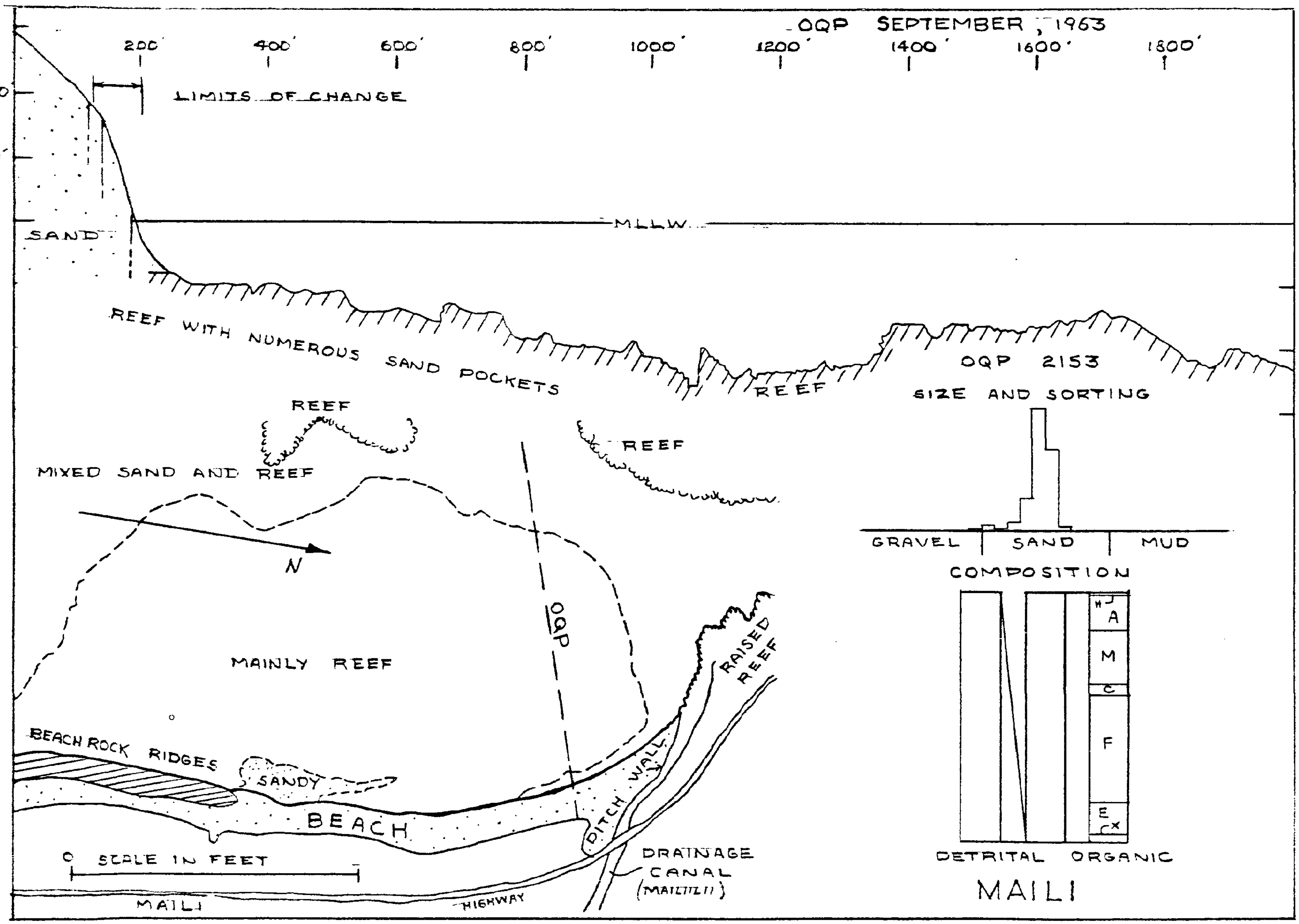
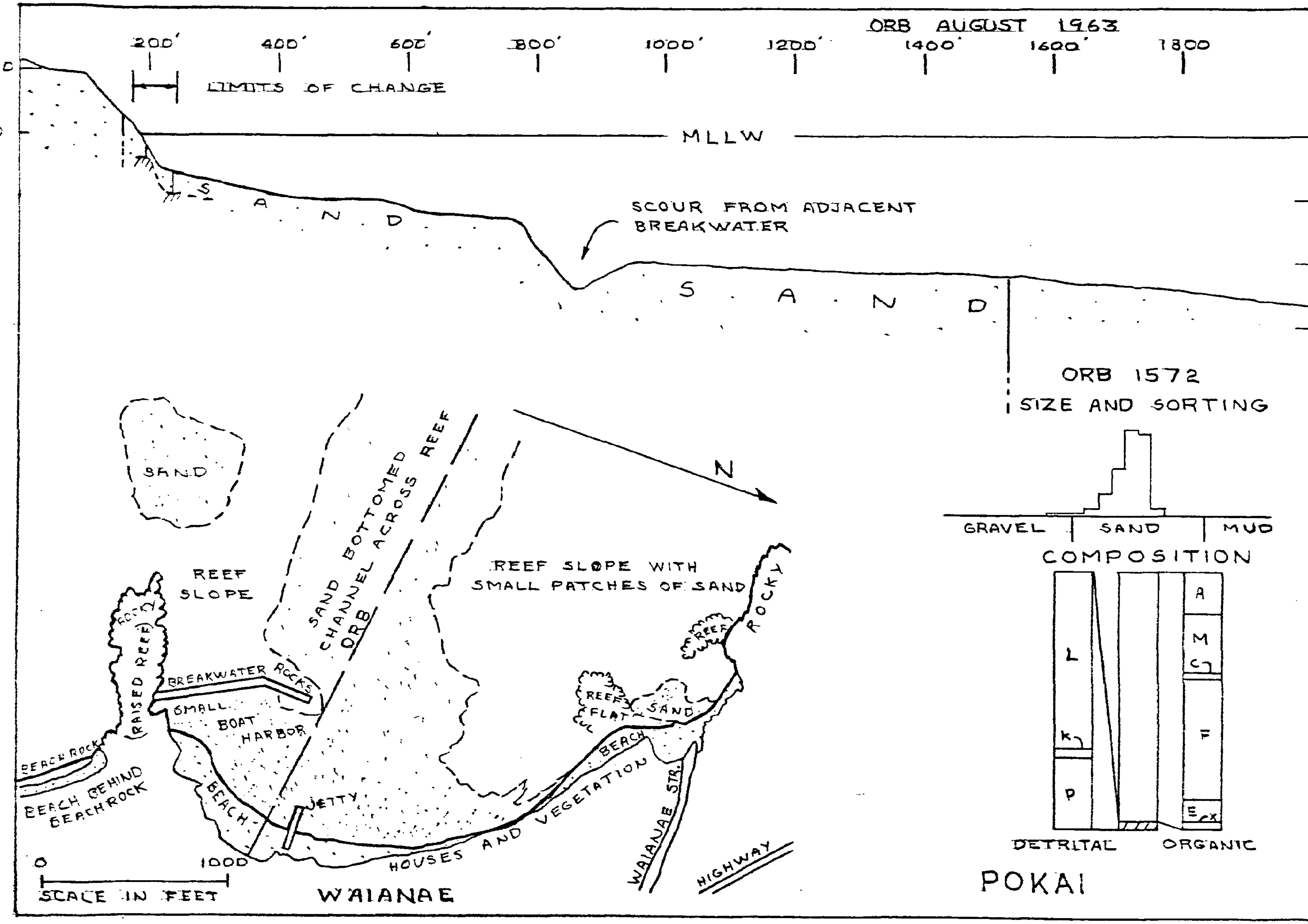

OQP SEPTEMBER, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+20'
+10'
0
10'
20'
30'
LIMITS OF CHANGE
SAND
MLLW
REEF WITH NUMEROUS SAND POCKETS
REEF
OQP 2153
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
A
M
C
F
E
DETRITAL
ORGANIC
MAILI
MIXED SAND AND REEF
N
OQP
MAINLY REEF
RAISED REEF
BEACH ROCK RIDGES
SANDY
BEACH
DITCH WALL
DRAINAGE
CANAL
SCALE IN FEET
0
MAILI
HIGHWAY

Fig. 26



ORB AUGUST 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800
+10
0
LIMITS OF CHANGE
MLLW
-10'
-20'
-30'
SAND
SCOUR FROM ADJACENT BREAKWATER
SAND
ORB 1572
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
L
K
P
A
M
C
F
E
X
DETRITAL
ORGANIC
POKAI
SAND
REEF SLOPE
SAND BOTTOMED CHANNEL ACROSS REEF
ORB
N
REEF SLOPE WITH SMALL PATCHES OF SAND
ROCKY
REEF
ROCKY
RAISED REEF
BREAKWATER ROCKS
SMALL BOAT HARBOR
REEF FLAT
SAND
BEACH ROCK
BEACH BEHIND BEACHROCK
BEACH
JETTY
BEACH
HOUSES AND VEGETATION
WAIANAE STR.
HIGHWAY
0
1000
SCALE IN FEET
WAIANAE

Fig. 27

sand is dredged and trucked to the north.

The calcareous sand is medium sized and only moderately-well sorted.

The reef slope has about 10% of its surface thinly covered with sediment that apparently is being driven shoreward by the waves. The water circulation pattern in Pokai Bay shows that the water moves seaward from mid-bay where there is the head of a sand-filled channel that crosses the reef.

Further comments on sand and water movement at Pokai Bay are to be found in a later section of this report.

Makaha O-5. (Figure 28.) Makaha Beach is at the north end of the mouth of Makaha Valley on the leeward coast of Oahu. The beach is arcuate and about 2000 feet long, limited at each end by low, rocky points that are raised reefs. This beach is subject to considerable seasonal variations in width. During the period of study the width changed from 225 feet in June to 80 feet the following January. This variation is probably due to the high surf that is refracted from the North Pacific swell during the winter. This surf also makes Makaha one of the better-surfing beaches on the island. The large changes in beach width have made it necessary to put in a revetment to protect the public bathhouse at the back of the beach.

The slope of this beach also varies, depending on the time of year, from a steep one in winter to a nearly flat one in summer.

The sand here is medium sized and quite well sorted. The sand is about 80% calcareous, with foraminifera and mollusk-shell fragments in great abundance.

The sand-bottomed channel across the reef is opposite the mouth of Makaha Stream. Most of the time the beach blocks the stream, but in times of flood the stream crosses the beach in a channel that shifts its position markedly.

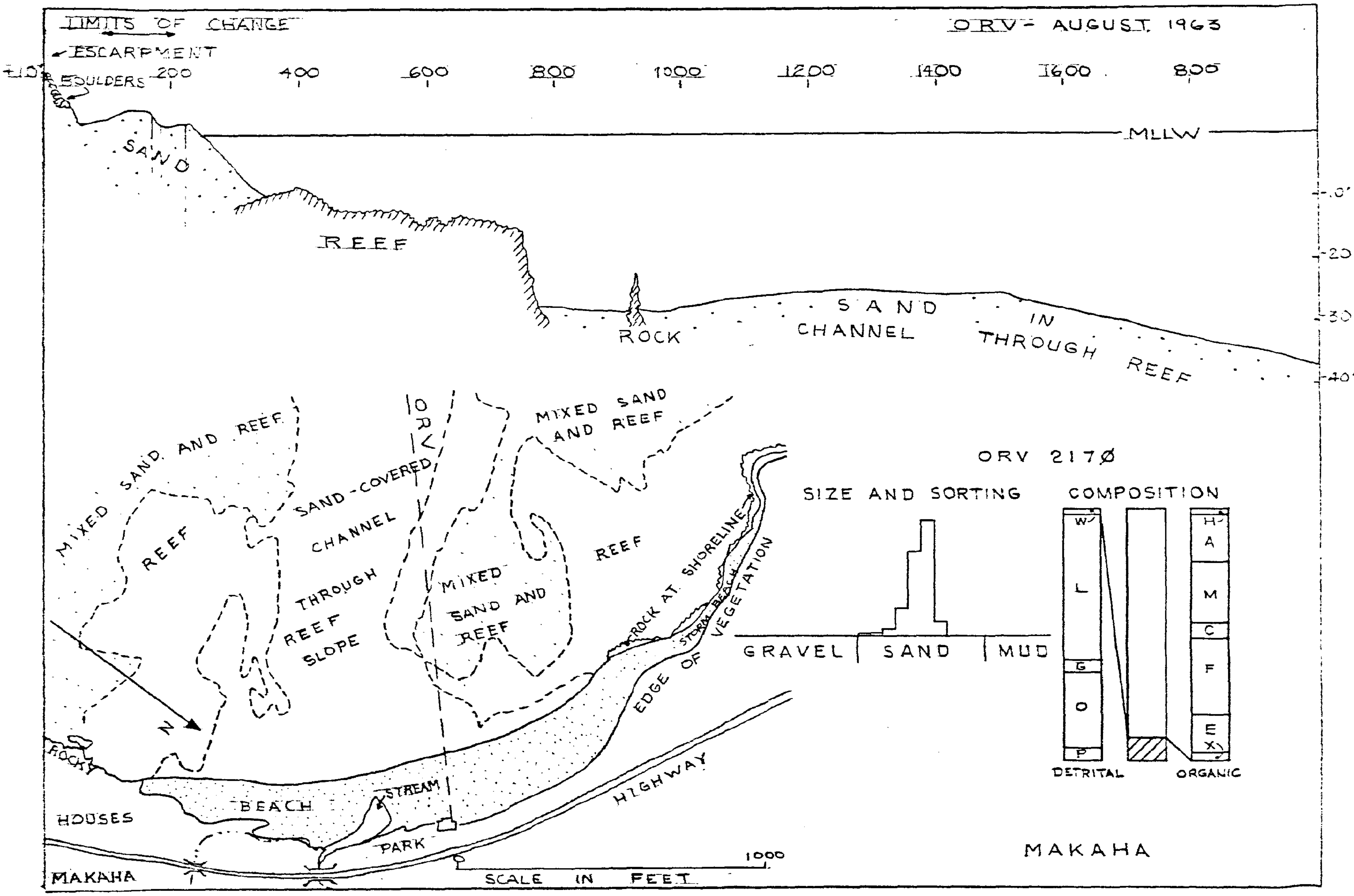
Keawaula 0-5. (Figure 29.) Keawaula Beach is known to many local residents as Yokohama Beach. It is the northwesternmost of the beaches on the leeward coast of Oahu. Keawaula Beach is about 3000 feet long, with an additional 2000 feet of storm beach at its northwest end. The beach is straight, with a width that varies from about 225 feet in the summer to 100 feet in the winter. When the beach is eroded back, the fore beach is not sand but a line of large boulders.

The sand is medium sized and very well sorted. Its composition is almost entirely calcareous, and foraminifera are the largest component.

Offshore, the distribution of reef and sand is very uneven. There is no distinct, sand-bottomed channel across the reef, as is so typical of Oahu beaches.

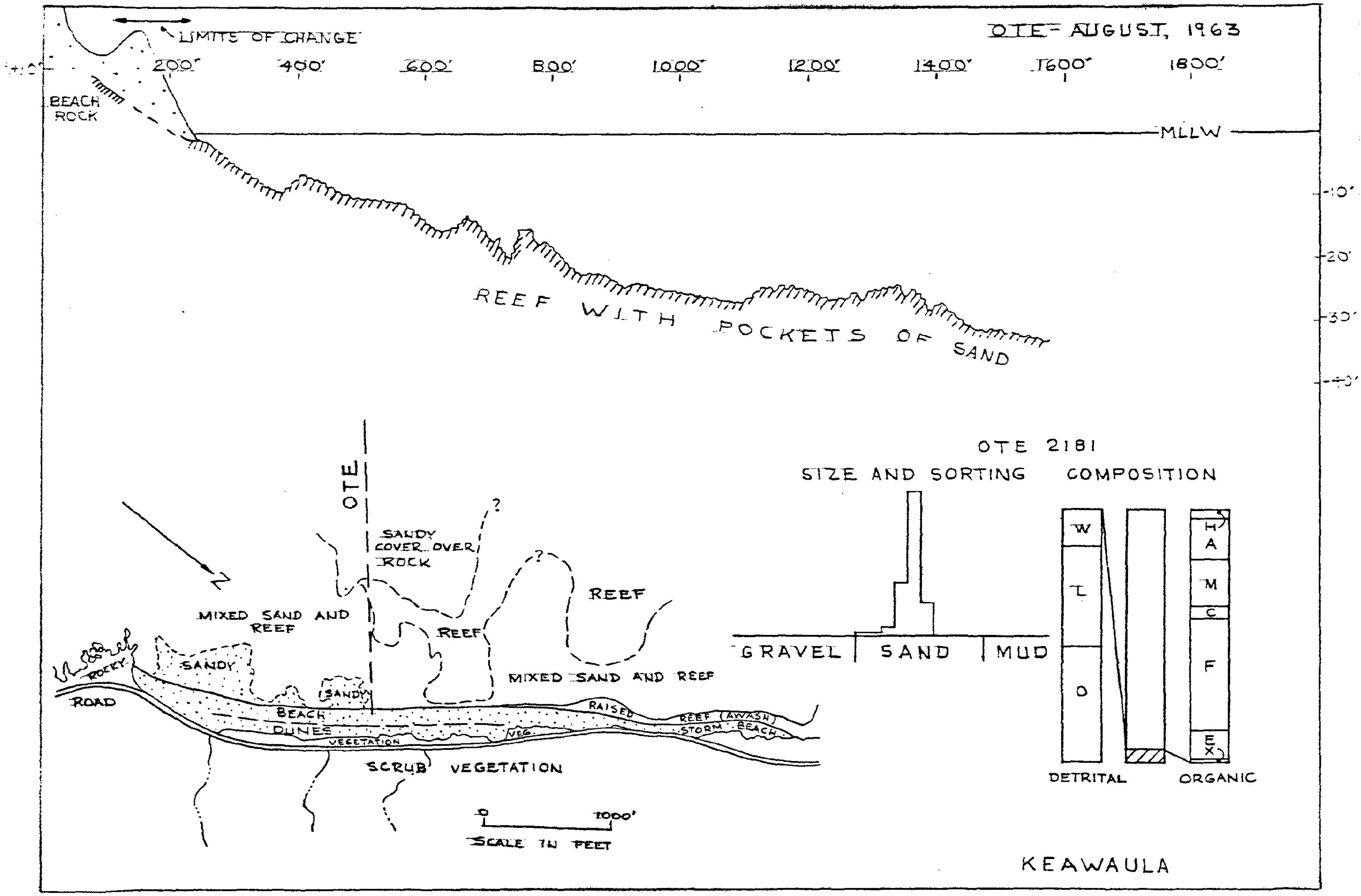
Swimming is fairly good here when the water is calm, but, because of the distance from Honolulu and the lack of public facilities, the beach is used only by surfers.

Camp Erdman 0-6. (Figure 30.) The beach at Camp Erdman is the western end of a 6-mile length of beach and beachrock, known generally as Mokuleia Beach, on the western part of Oahu's north coast. Near Camp Erdman the beach varies in width from 25 to 150 feet, with seasonal variations in the width of up to 50 feet recorded during the period of the study.



LIMITS OF CHANGE
ESCARPMENT
BOULDERS
ORV - AUGUST 1963
+10'
200
400
600
800
1000
1200
1400
1600
800
MLLW
-10'
-20'
-30'
-40'
SAND
REEF
ROCK
SAND CHANNEL IN THROUGH REEF
MIXED SAND AND REEF
REEF
SAND-COVERED CHANNEL THROUGH REEF SLOPE
ORV
MIXED SAND AND REEF
MIXED SAND AND REEF
REEF
ROCK AT SHORELINE
STORM BEACH
EDGE OF VEGETATION
N
ROCKY
HOUSES
BEACH
STREAM
PARK
HIGHWAY
MAKAHA
SCALE IN FEET
1000
ORV 217Ø
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
O
P
DETRITAL
H
A
M
C
F
E
X
ORGANIC
MAKAHA

Fig. 28



OTE - AUGUST, 1963
LIMITS OF CHANGE
+10'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
BEACH ROCK
MLLW
-10'
-20'
-30'
-40'
REEF WITH POCKETS OF SAND
OTE 2181
SIZE AND SORTING
COMPOSITION
GRAVEL
SAND
MUD
W
L
O
H
A
M
C
F
EX
DETRITAL
ORGANIC
OTE
N
SANDY COVER OVER ROCK
REEF
MIXED SAND AND REEF
REEF
MIXED SAND AND REEF
SANDY
SANDY
ROCKY
ROAD
BEACH
DUNES
VEGETATION
VEG.
RAISED
REEF (AWASH)
STORM BEACH
SCRUB VEGETATION
0
1000'
SCALE IN FEET
KEAWAULA

Fig. 29

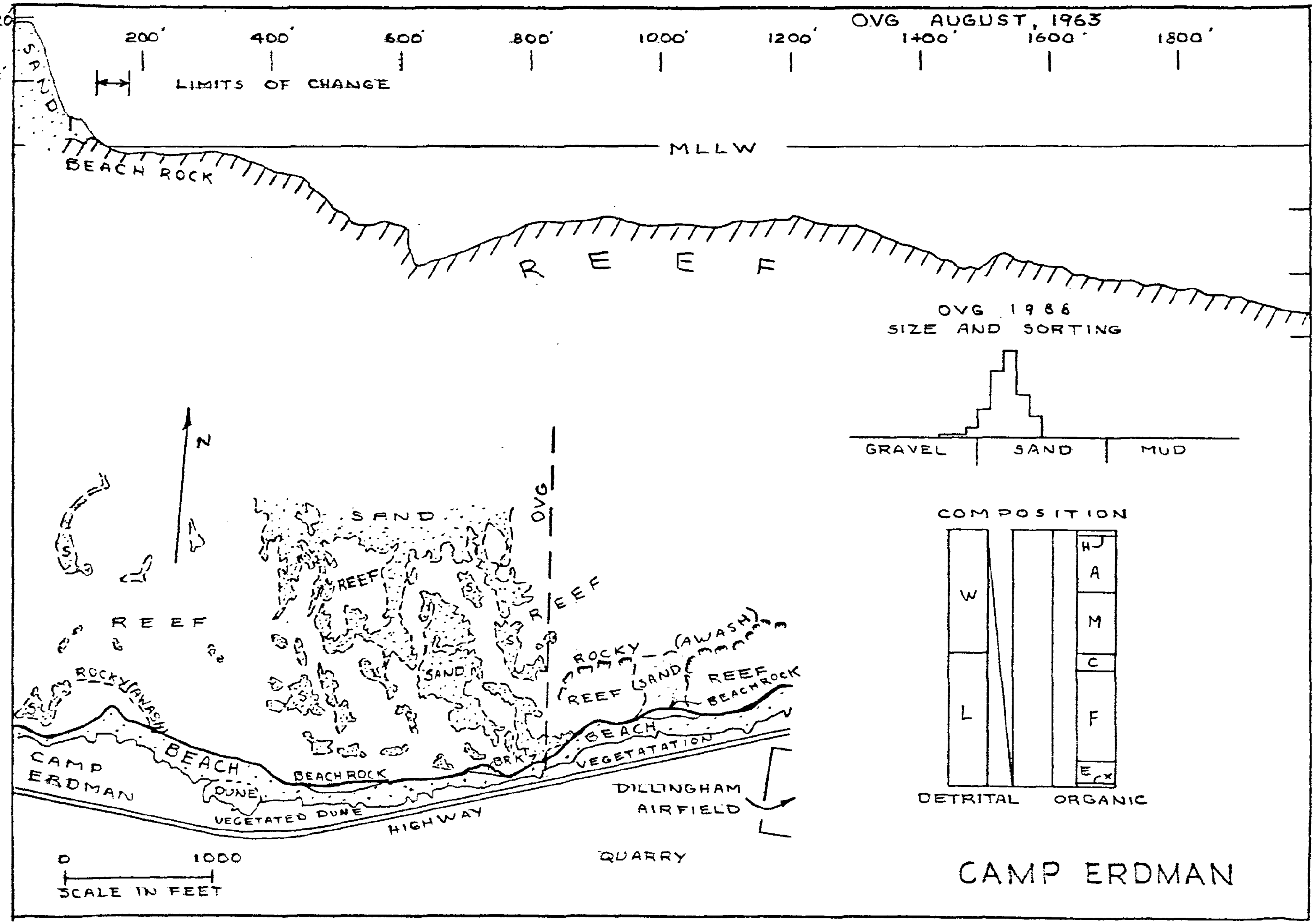

OVG AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+20'
+10'
0
-10'
-20'
-30'
SAND
LIMITS OF CHANGE
MLLW
BEACH ROCK
REEF
OVG 1986
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
H
J
A
M
C
F
E
X
DETRITAL
ORGANIC
N
OVG
SAND
REEF
ROCKY
AWASH
BEACH
CAMP ERDMAN
DUNE
VEGETATED DUNE
BEACH ROCK
BRK
VEGETATATION
HIGHWAY
DILLINGHAM AIRFIELD
QUARRY
0
1000
SCALE IN FEET
CAMP ERDMAN

Fig. 30

The sand here is medium- to coarse-grained and poorly sorted, with about 10 percent detrital grains and the remainder calcareous.

Beachrock crops out along part of the beach and immediately offshore. These rocks, together with bad currents, make this beach undesirable as a swimming beach.

Two or three years ago there was a siege of bad erosion along this beach. There had been a large sand-mining pit immediately east of Camp Erdman and, when the waves broke through the front of the pit, sand was eroded all along the beach and moved to fill the pit. Once the pit was filled, erosion stopped. There is now a new sand-mining pit in dunes inland of the road near the middle of the beach. Exploitation of these old dunes should have no effect on the beach.

Mokuleia 0-6. (Figure 31.) The middle part of Mokuleia Beach, near the Episcopal Church Camp, is an arcuate beach about $\frac{1}{2}$-mile long that is roughly the same width over its entire length. The beach is narrow, about 30 feet wide, and varies in width by only 15 feet over the period of the study. Most of this change was a result of severe erosion that occurred last winter when a 4-foot-high scarp was cut into the low dune ridge back of the beach, and a number of ironwood trees were badly undermined.

The west end of this beach is held by a spit-like length of beachrock that marks the position of an ancient beach. The eastern end is a broad point that apparently was formed by advancing beach ridges, although beachrock there suggests that the latest event was minor erosion. In a shallow bay immediately east of that broad point there is the head of a sand-bottomed channel which has cut diagonally across the reef.

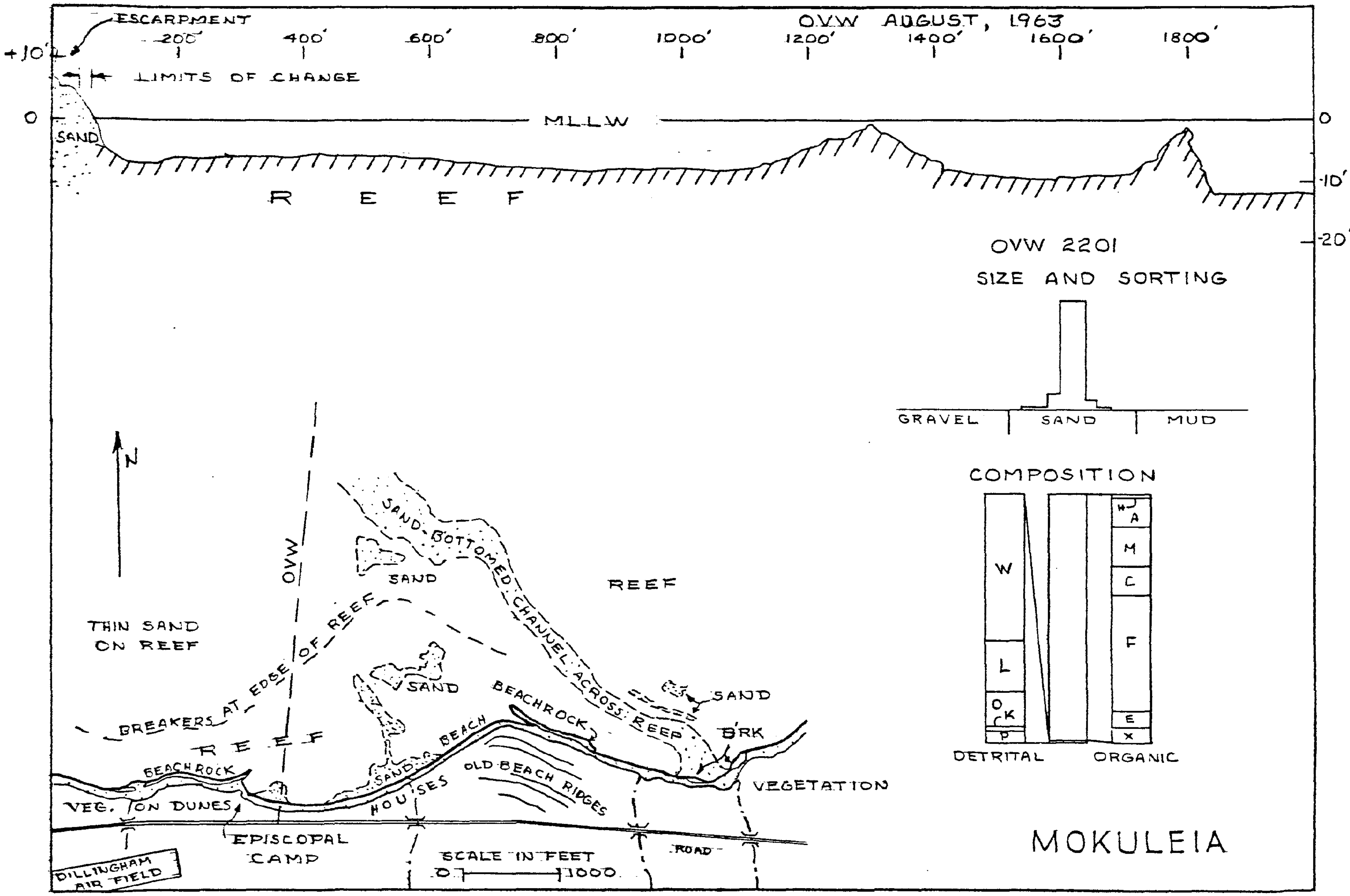
The sand is nearly all calcareous material of medium size and is well sorted. The swimming is not very good here even though the beach is fairly well protected, because the bottom is rocky and the water is often dirty.

Wailua O-6. (Figure 32.) Formerly there were three main beach areas around Wailua Bay on the north-central Oahu coast. A large beach on the east side of the bay, at the present beach park, was eroded away in the middle and late 1940's. according to local residents. A part of that beach still remains, at its southwest end, as a barrier beach of Anahulu River.

A second beach is on the broad point dividing the bay into two arms. This beach was studied most completely. Over the period of the study this beach varied in width from 175 feet to 200 feet. The change appeared to be seasonal, with the beach being widest in the summer. The east end of the beach is a breakwater and the west end has several outcrops of beachrock at the shoreline. The sand is medium to coarse grained and predominantly calcareous.

The swimming is poor here due to the shallow reef off the beach and the frequency of dangerous currents. During the winter when waves are high this is a popular surfing beach.

A third beach is on the shore of the southwestern arm of Wailua Bay and is used as an armed forces recreation center. Swimming is fairly good inasmuch as the water is deep close to shore because the head of a sand-bottomed channel cuts here diagonally across the reef. The channel joins a second one under the east arm of the bay.



ESCARPMENT
+10'
0
LIMITS OF CHANGE
OVW AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
SAND
-10'
-20'
R E E F
OVW 2201
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
K
P
A
M
C
F
E
X
DETRITAL
ORGANIC
N
OVW
SAND-BOTTOMED CHANNEL ACROSS REEF
SAND
REEF
THIN SAND ON REEF
BREAKERS AT EDGE OF REEF
R E E F
BEACHROCK
BRK
VEGETATION
BEACH
OLD BEACH RIDGES
HOUSES
VEG. ON DUNES
EPISCOPAL CAMP
DILLINGHAM AIR FIELD
SCALE IN FEET
0
1000
ROAD
MOKULEIA

Fig. 31

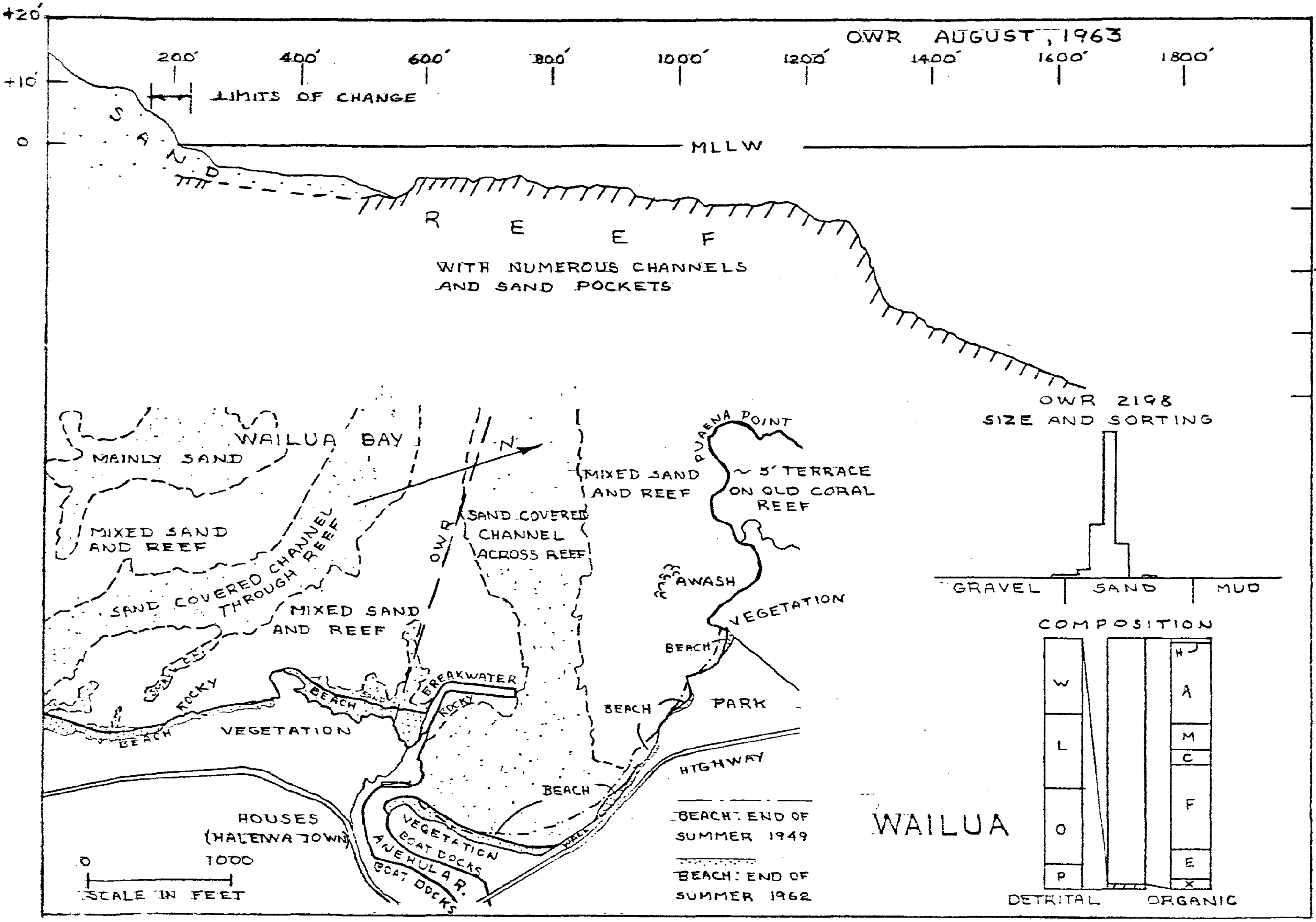

OWR AUGUST, 1963
+20'
+10'
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
SAND
MLLW
REEF
WITH NUMEROUS CHANNELS AND SAND POCKETS
-10'
-20'
-30'
-40'
OWR 2198
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
P
H
J
A
M
C
F
E
X
DETRITAL
ORGANIC
WAILUA
WAILUA BAY
MAINLY SAND
MIXED SAND AND REEF
SAND COVERED CHANNEL THROUGH REEF
MIXED SAND AND REEF
N
OWR
SAND COVERED CHANNEL ACROSS REEF
MIXED SAND AND REEF
PUAENA POINT
~ 5' TERRACE ON OLD CORAL REEF
AWASH
VEGETATION
BEACH
PARK
BEACH
HIGHWAY
BEACH
BREAKWATER
ROCKY
BEACH
SAND
ROCKY
BEACH
VEGETATION
HOUSES (HALEIWA TOWN)
VEGETATION
BOAT DOCKS
ANAHULU R.
BOAT DOCKS
WALL
0
1000
SCALE IN FEET
BEACH: END OF SUMMER 1949
BEACH: END OF SUMMER 1962

Fig. 32

Kawailoa O-7. (Figure 33.) Kawailoa Beach is a 2-mile long beach broken by numerous outcrops of lava and beachrock. The south-central part is a 3/4-mile long, relatively straight beach that averages about 125 feet in width in the middle and tapers to 75 feet wide near the ends. The beach changes seasonally, being eroded about 40 feet during the winter.

The highly calcareous sand is of medium grain size.

The shallow water and abundance of reef leads to generally poor swimming except in some of the sand-bottomed pockets on the reef. Surf in the winter can be very dangerous.

Waimea O-7. (Figure 34.) Waimea River has a bayhead barrier beach where it enters Waimea Bay on northern Oahu. The slightly arcuate pocket beach is about 1500 feet long and 150 feet wide. The width of the beach varies seasonally, with the sand from the southwest end moving to the northeast during the winter, and then moving back in the summer. Some sand may also move offshore during the winter. Waimea beach has a steep foreshore in the winter and a flat one during the summer. There is generally one berm formed on the beach, but sometimes two. Cusps are a common occurrence, and the calcareous sand is well sorted and of medium-grain size.

The swimming here is extremely dangerous when waves are high because large rip currents are generated in the bay. However, it is a popular beach in the summer.

This beach was extensively mined as recently as the winter of 1961-62.

Sunset Beach O-7. (Figure 35.) Sunset Beach is the longest wide beach on Oahu. At the waterline, outcrops of beachrock or raised reef occur at places seasonally; but the sand behind them is continuous. The beach is 2 miles long and averages about 200 feet wide. During the winter this beach is eroded severely, with the foreshore cut to a steep escarpment. During the summer the foreshore slope is relatively gentle, and often along the beach there can be found one or two berms with cusps cut in them. The calcareous sand is poorly sorted, medium to coarse in grain size.

Under most conditions, swimming is quite dangerous at Sunset Beach. When waves are high during the winter, this beach has some of the highest surf to be found anywhere in the State.

North of Laie Bay O-8. (Figure 36.) An unnamed bay between Laie and Kahuku near the northern end of windward Oahu has a narrow beach. The bay resembles Laie Bay, adjacent to the south, in that it is a scallop between points of eolianite and is protected offshore by eolianite islands and a reef, but it differs from Laie Bay in that it does not have a distinct channel cutting across the reef from the middle of the bay.

The beach itself is crescentic in shape, about 6000 feet in length and generally varying in width between 50 and 100 feet at its south end, and between 100 and 200 feet at its north end. There is no berm development under present conditions, but a sandy, vegetated terrace may represent an old berm. The terrace is bordered inland by a vegetated old dune ridge on which houses are built, and to seaward it is cut by a low escarpment at the inner edge of the beach.

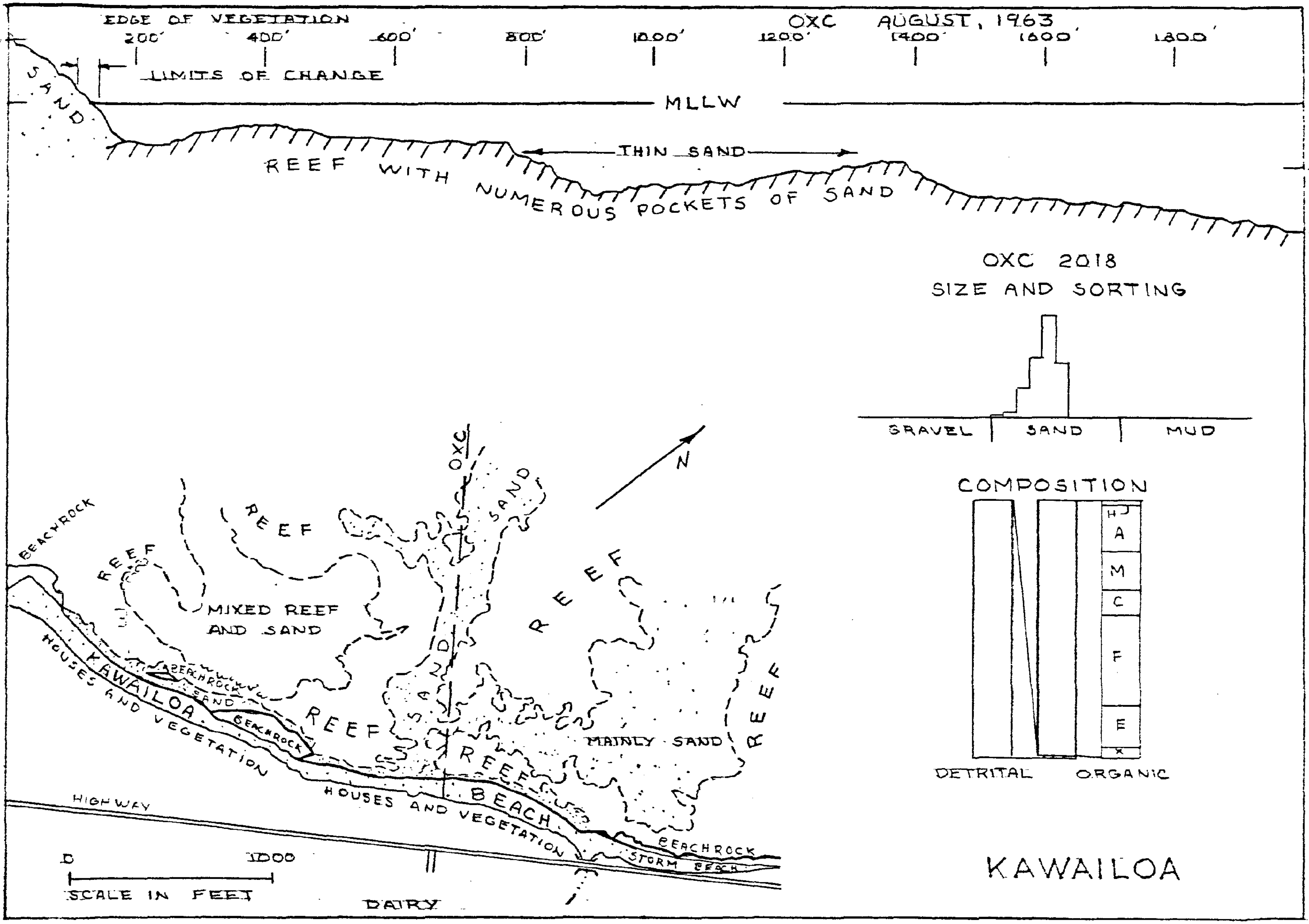

OXC AUGUST, 1963
EDGE OF VEGETATION
LIMITS OF CHANGE
+10
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
-10'
-20'
SAND
THIN SAND
REEF WITH NUMEROUS POCKETS OF SAND
OXC 2018
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
H
J
A
M
C
F
E
X
DETRITAL
ORGANIC
KAWAILOA
N
OXC
BEACHROCK
REEF
MIXED REEF AND SAND
SAND
MAINLY SAND
KAWAILOA
BEACH
STORM BEACH
HOUSES AND VEGETATION
HIGHWAY
DAIRY
0
1000
SCALE IN FEET

Fig. 33

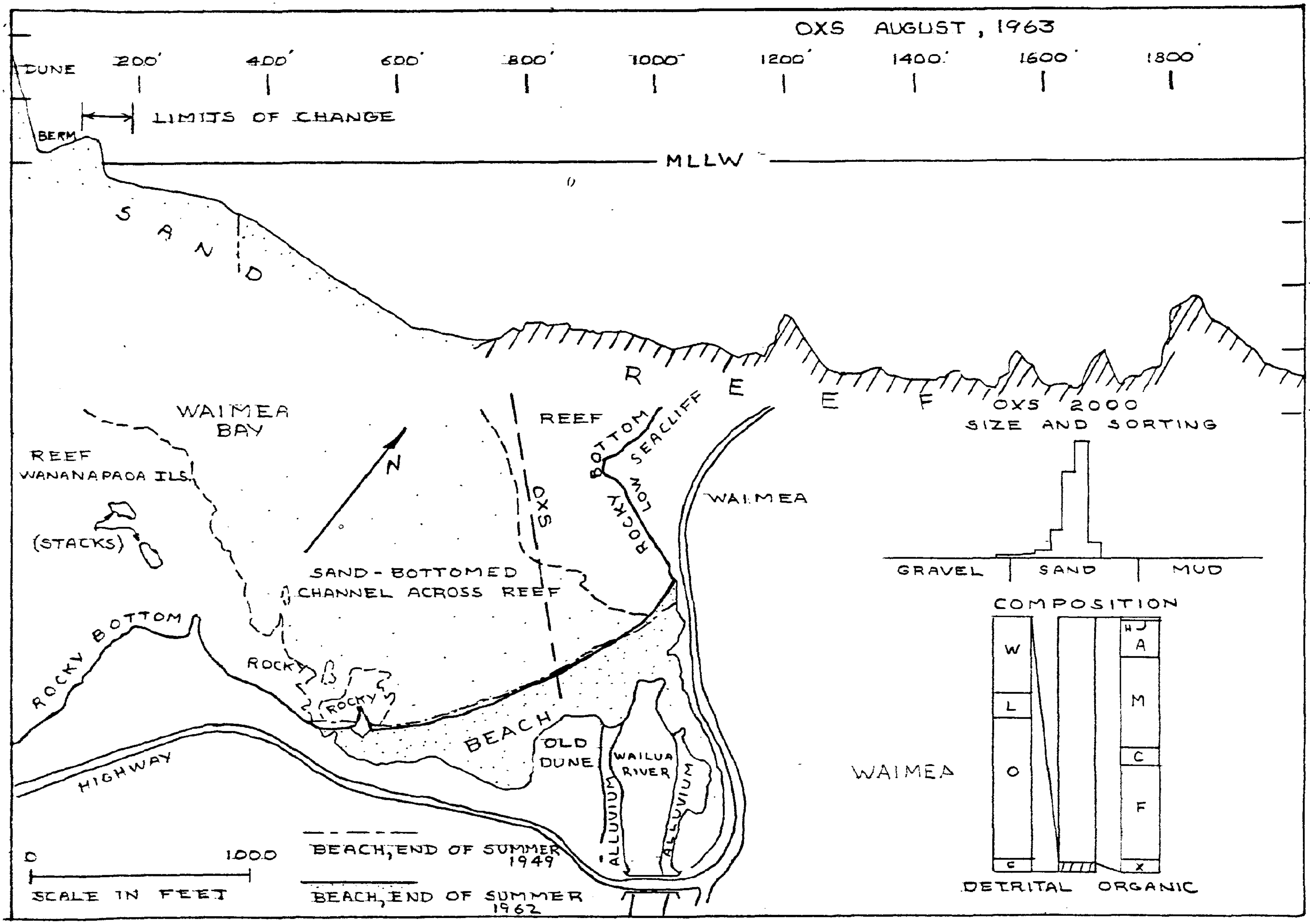

OXS AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
-20'
-10'
0
-10'
-20'
-30'
-40'
DUNE
BERM
LIMITS OF CHANGE
MLLW
SAND
REEF
WAIMEA BAY
REEF
WANANAPAOA ILS.
(STACKS)
N
SAND-BOTTOMED CHANNEL ACROSS REEF
OXS
REEF
BOTTOM
LOW SEACLIFF
ROCKY
WAIMEA
ROCKY BOTTOM
ROCKY
ROCKY
BEACH
OLD DUNE
WAILUA RIVER
ALLUVIUM
ALLUVIUM
HIGHWAY
WAIMEA
0
1000
SCALE IN FEET
BEACH, END OF SUMMER 1949
BEACH, END OF SUMMER 1962
OXS 2000
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
c
H
J
A
M
C
F
x
DETRITAL
ORGANIC

Fig. 34

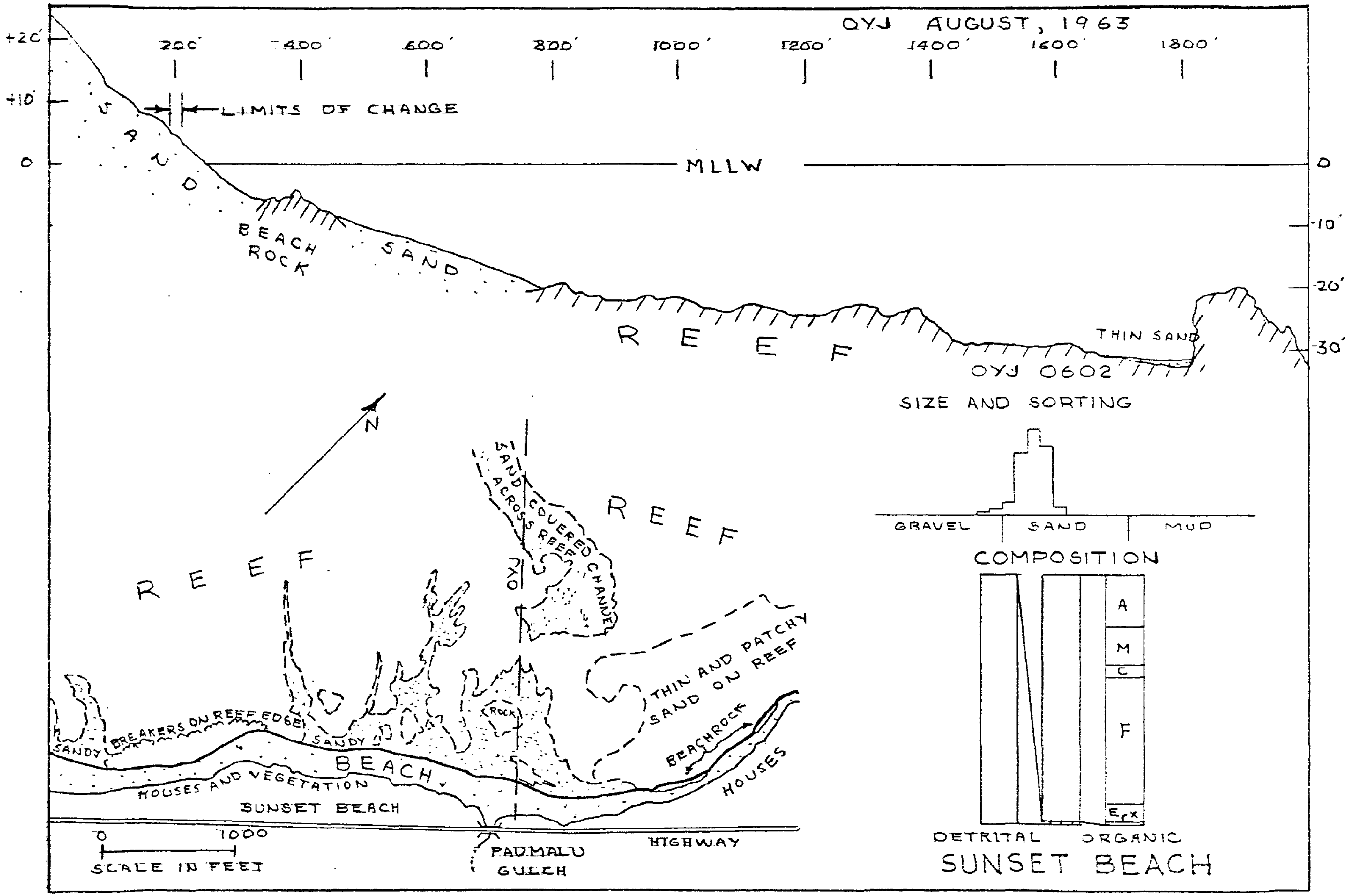

OYJ AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+20'
+10'
0
MLLW
-10'
-20'
-30'
LIMITS OF CHANGE
SAND
BEACH ROCK
SAND
REEF
THIN SAND
OYJ 0602
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
A
M
C
F
DETRITAL
ORGANIC
SUNSET BEACH
N
REEF
REEF
SAND COVERED CHANNEL ACROSS REEF
OYJ
THIN AND PATCHY SAND ON REEF
ROCK
BREAKERS ON REEF EDGE
SANDY
SANDY
BEACH
BEACHROCK
HOUSES AND VEGETATION
HOUSES
SUNSET BEACH
HIGHWAY
PAUMALU GULCH
0
1000
SCALE IN FEET

Fig. 35

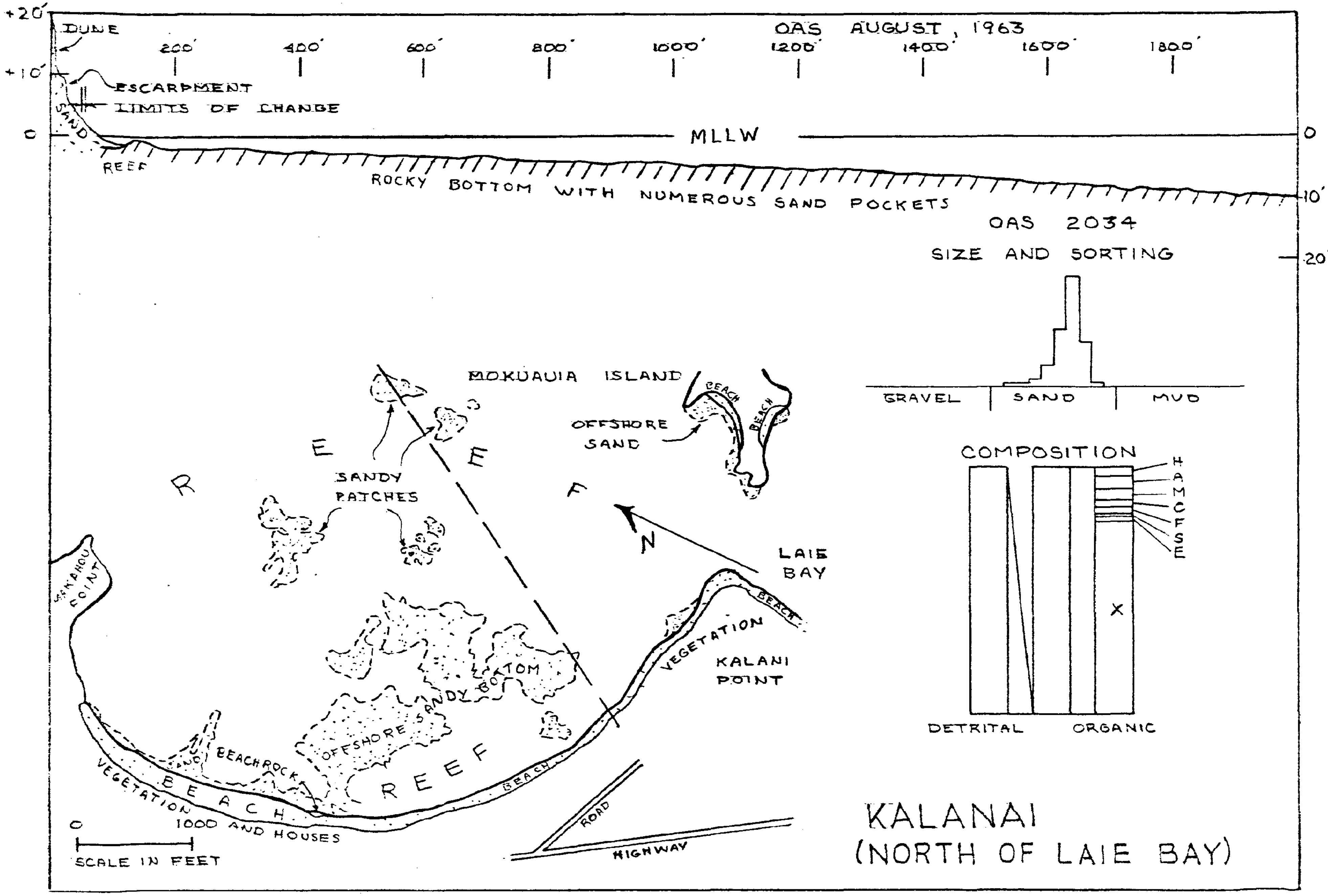

OAS AUGUST, 1963
+20'
+10'
0
-10'
-20'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
DUNE
ESCARPMENT
LIMITS OF CHANGE
SAND
REEF
MLLW
ROCKY BOTTOM WITH NUMEROUS SAND POCKETS
OAS 2034
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
H
A
M
C
F
S
E
X
DETRITAL
ORGANIC
MOKUAUIA ISLAND
BEACH
OFFSHORE SAND
SANDY PATCHES
R E E F
N
LAIE BAY
VEGETATION
KALANI POINT
SANDY BOTTOM
OFFSHORE SANDS
BEACHROCK
B E A C H
VEGETATION AND HOUSES
KAHAHOU POINT
ROAD
HIGHWAY
0
1000
SCALE IN FEET
KALANAI
(NORTH OF LAIE BAY)

Fig. 36

The sand is almost entirely calcareous and moderately well sorted and fine grained. Because of the fine-grain size, few specific organisms could be identified as contributors to the sand.

There is rock exposed at the shoreline near the north end of the bay, and a small patch of beachrock is exposed in the middle of the beach. Under typical tradewind conditions, low waves, refracted around the small islands and points of land, spread across the bay and plunge within a few feet of the shore.

Laie 0-8. (Figure 37.) Laie Beach is concave seaward at the center for about 2000 feet, then broadly convex seaward on both sides. Altogether the beach is about $1\frac{1}{2}$ miles long and 70 feet wide, and about the same width along its entire length. Inland from Laie Beach there is a flat plain composed of consolidated calcareous material. The bottom offshore is mostly reef with one large sand-bottomed channel cutting across it.

The beach has a relatively steep foreshore which usually extends back to the grass, although sometimes a small berm may develop. The sand is medium sized with fair sorting. There were a few detrital grains in the sand which was composed mainly of foraminifera skeletons.

This beach is fairly good for swimming and body surfing, although the water is sometimes dirty because of streams that enter nearby. Laie Beach is a renowned commercial hukilau and luau beach.

North Hauula 0-8. (Figure 38.) A narrow but attractive beach lies on the shores of a shallow unnamed bay midway between Laie and Hauula on windward Oahu. This beach is slightly arcuate, concave seaward, with a small rocky point to the north and a broad, rocky and sandy point to the southeast. The beach is about 2000 feet long and varied in width from 30 feet in June 1962, to 75 feet in March 1963.

Behind the beach is a line of houses and the highway. Generally the inner edge of the foreshore is at the contact of the beach and the grass, but at times there is a small berm of the beach itself. Occasionally, cusps form along the beach. There is sandy bottom immediately offshore along most of the beach. Under some conditions a moderately strong alongshore current is generated.

The sand is medium- to coarse-grained with poor sorting. The sand is nearly all calcareous material, with the largest constituent being foraminifera.

The head of a large, steep-walled, sand-bottomed channel is close to shore in the middle part of the bay. The reef off the south part of the beach is very wide and shallow.

Hauula 0-8. (Figure 39.) Hauula Beach is fairly straight, about 1000 feet long and generally very narrow along its entire length. During the study, the width of the beach varied from 15 to 35 feet. There is no berm along the beach which has a moderately steep foreshore.

In the area most closely observed, Hauula Park, a row of ironwood trees is being undermined by wave erosion. The waves are seldom very big here because of the shallow reef offshore, but there is little beach between the waves and the trees. The reef also makes this a poor spot for swimming. A sand-bottomed channel crosses the reef north of the beach park.

The sand is of medium-grain size and is fairly well sorted. About four-fifths of the sand is calcareous.

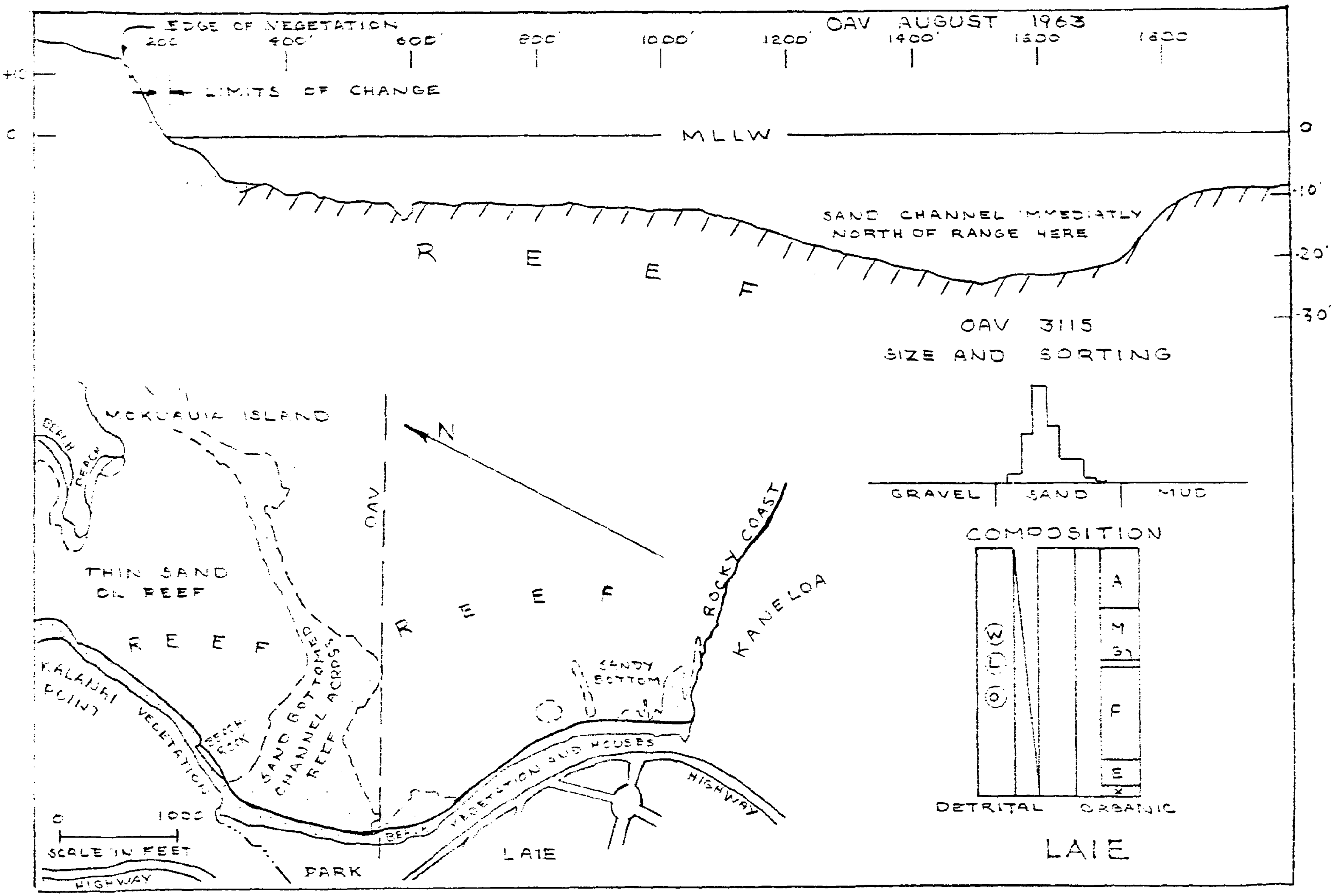

OAV AUGUST 1963
EDGE OF VEGETATION
200
400'
600'
800'
1000'
1200'
1400'
1600
1800
LIMITS OF CHANGE
+10
0
MLLW
0
-10'
-20'
-30'
SAND CHANNEL IMMEDIATLY
NORTH OF RANGE HERE
R E E F
OAV 3115
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
A
M
F
E
x
DETRITAL
ORGANIC
LAIE
MOKUAUIA ISLAND
BEACH
THIN SAND
ON REEF
REEF
KALANAI
POINT
VEGETATION
BEACH ROCK
SAND BOTTOMED
CHANNEL ACROSS
REEF
OAV
N
R E E F
ROCKY COAST
KANELOA
SANDY
BOTTOM
VEGETATION AND HOUSES
HIGHWAY
0
1000
SCALE IN FEET
HIGHWAY
PARK
LAIE

Fig. 37

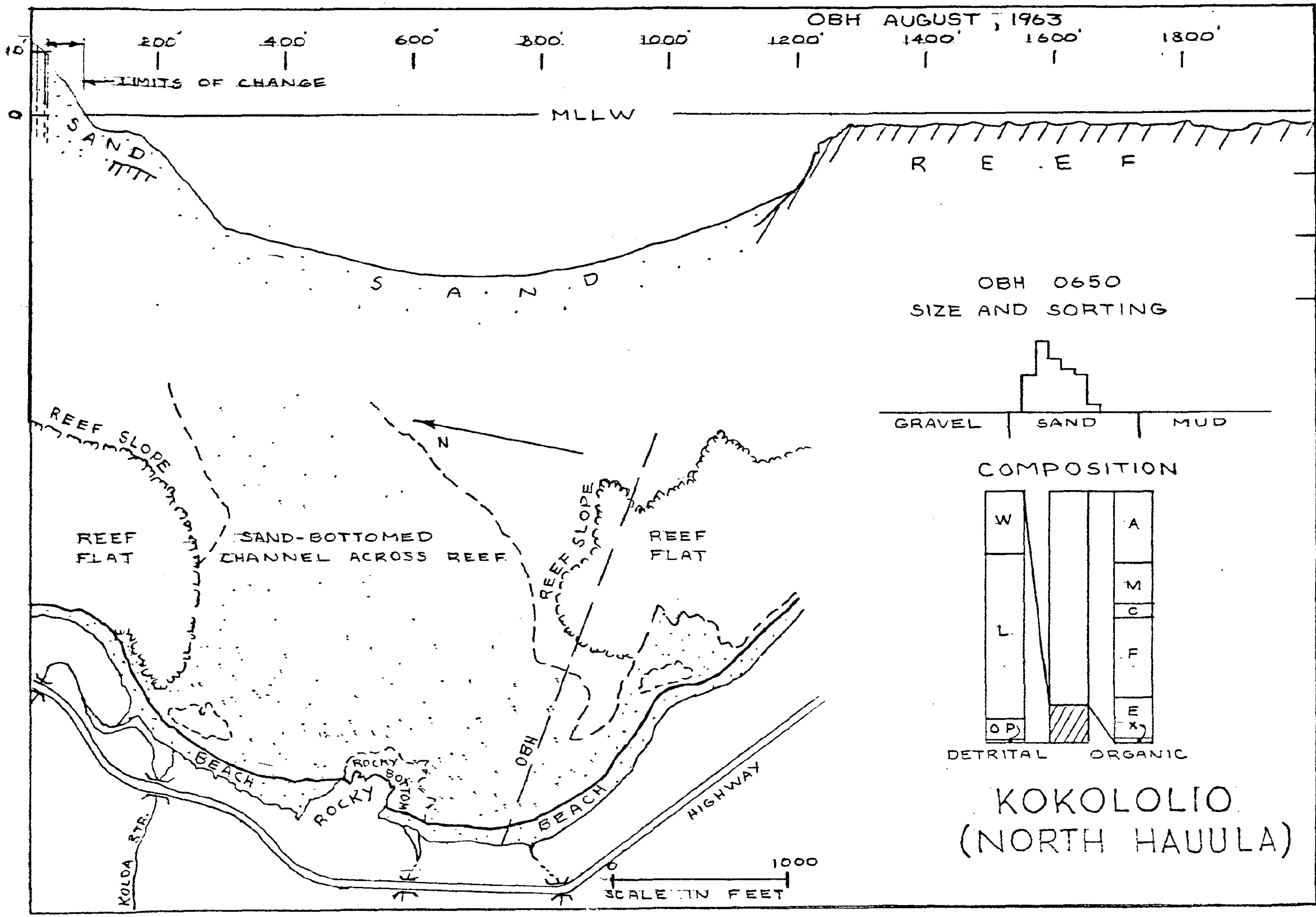

OBH AUGUST, 1963
200' 400' 600' 800' 1000' 1200' 1400' 1600' 1800'
10' 0
LIMITS OF CHANGE
MLLW
0 10' 20' 30'
SAND
REEF
SAND
OBH 0650
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
OP
A
M
C
F
E
X
DETRITAL
ORGANIC
KOKOLOLIO
(NORTH HAUULA)
REEF SLOPE
REEF FLAT
SAND-BOTTOMED CHANNEL ACROSS REEF
N
REEF SLOPE
REEF FLAT
OBH
ROCKY BOTTOM
ROCKY
BEACH
BEACH
HIGHWAY
KOLOA STR.
0 1000
SCALE IN FEET

Fig. 38

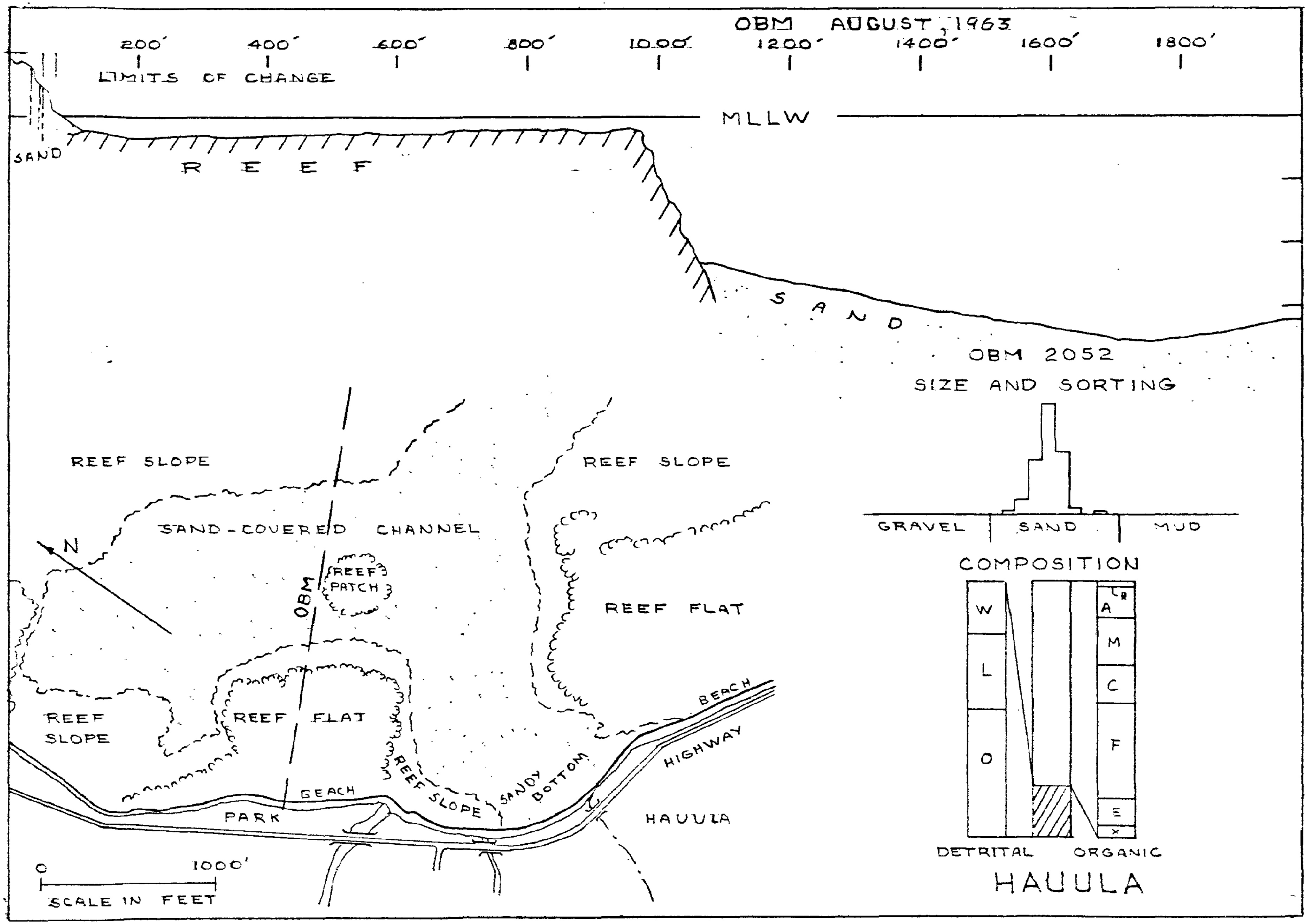

OBM AUGUST, 1963
10'
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
MLLW
SAND
REEF
10'
20'
30'
SAND
OBM 2052
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
A
M
C
F
E
X
DETRITAL
ORGANIC
HAUULA
REEF SLOPE
REEF SLOPE
SAND-COVERED CHANNEL
N
REEF PATCH
OBM
REEF FLAT
REEF SLOPE
REEF FLAT
BEACH
PARK
REEF SLOPE
SANDY BOTTOM
BEACH
HIGHWAY
HAUULA
0
1000'
SCALE IN FEET

Fig. 39

Punaluu 0-8. (Figure 40.) Punaluu Beach is a narrow, relatively straight beach about $\frac{1}{2}$-mile long. The beach is uniform in width, except that it is about twice as wide near the place where a drainage ditch crosses it. During the study the width of the beach varied from 35 to 60 feet. The beach generally had a very low gradient because most of the waves break on the shallow reef that protects most of the beach and not on the beach itself.

Large piles of sand near the range along which profiles were measured were indications that sometime between 2 March 1963 and 4 May 1963 sand was added to the back beach. Whether this sand was trucked in, or brought in by wind or waves, is not known. The measurements made after March may not be directly comparable with the earlier ones.

The calcareous sand is of medium- to coarse-grain size and is very poorly sorted.

As is so common along the windward reef coast of Oahu, a steep-walled, sand-bottomed channel extends from near the beach across the reef. This channel had a small tributary channel to the south.

Kahana Bay 0-8. (Figure 41.) The barrier beach at the head of Kahana Bay is slightly concave seaward, and is about 3/4-mile long. The beach was about 40 feet wide with a low gradient, and cusps are often found along this beach. A storm in late April, 1963, cut this beach back about 100 feet, but by mid-August 50 feet of sand had returned.

Behind the beach is a narrow wooded strip and then the highway.The northwest end of the beach is the rocky shore of the valley side and on the east it ends at Kahana Stream. The swimming is fairly good here except when the water is dirty.

The sand is medium to fine in grain size and is poorly sorted.

The reef on the south side of the bay is very shallow. The sand-bottomed channel leading out from the mouth of the bay is one of the largest on Oahu. The sand in it is more than 15 feet in thickness.

Kailua O-10. (Figure 42.) Kailua Beach is about 2 miles long and varies in width from about 30 feet at the north end to 170 feet at the south end. This beach gained sand along its whole length in early winter, but lost it again in the early summer. Kailua Beach varies in steepness from flat at the south end to steep in the center to moderately steep at the north end. Behind the beach are old, vegetated dunes and some of the houses of the town of Kailua.

The highly calcareous beach sand is very poorly sorted and shows a tendency towards bimodality. Large but thin patches of sand are offshore. The general level of the reef-flat is deeper than many windward Oahu beaches.

There is good swimming and body surfing along most of this beach, and board surfing at the north end and near Popoia Island. Locally, alongshore currents might be dangerous, but only in rough weather. Generally, the only hazards are occasional stinging Portuguese man-of-war.

Lanikai O-10. (Figure 43.) Lanikai Beach is a nearly straight beach slightly more than 1-mile long and from 20 to 100 feet wide. This beach has been eroding along its northwest end and depositing sand

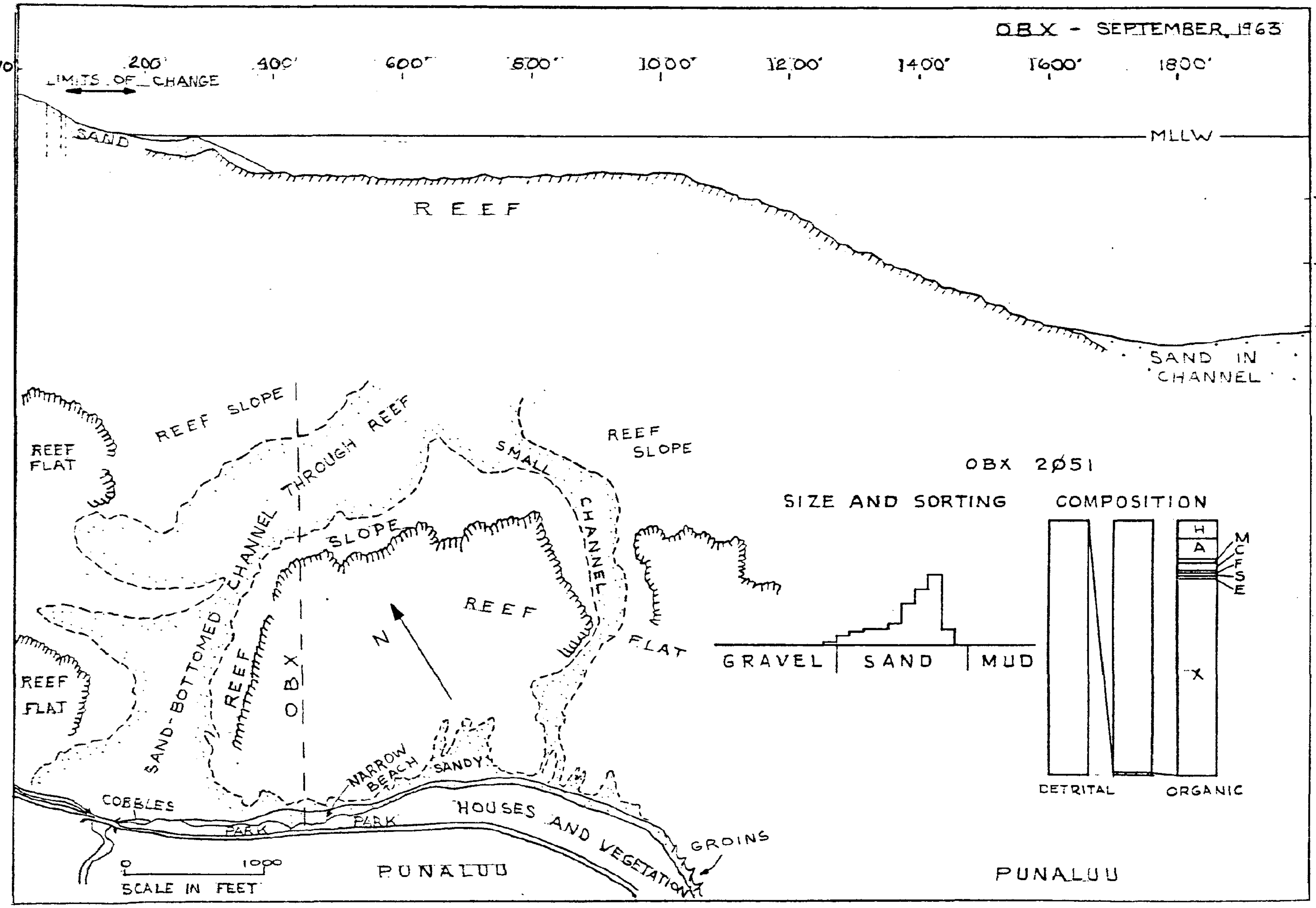

OBX - SEPTEMBER 1963
10
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
SAND
MLLW
REEF
-10'
-20'
-30'
SAND IN CHANNEL
REEF SLOPE
REEF FLAT
THROUGH REEF
CHANNEL
SLOPE
SMALL
CHANNEL
REEF SLOPE
REEF
FLAT
N
SAND-BOTTOMED
REEF
OBX
REEF FLAT
NARROW BEACH
SANDY
COBBLES
PARK
PARK
HOUSES AND VEGETATION
GROINS
0
1000
SCALE IN FEET
PUNALUU
OBX 2Ø51
SIZE AND SORTING
COMPOSITION
GRAVEL
SAND
MUD
H
A
M
C
F
S
E
X
DETRITAL
ORGANIC
PUNALUU

Fig. 40

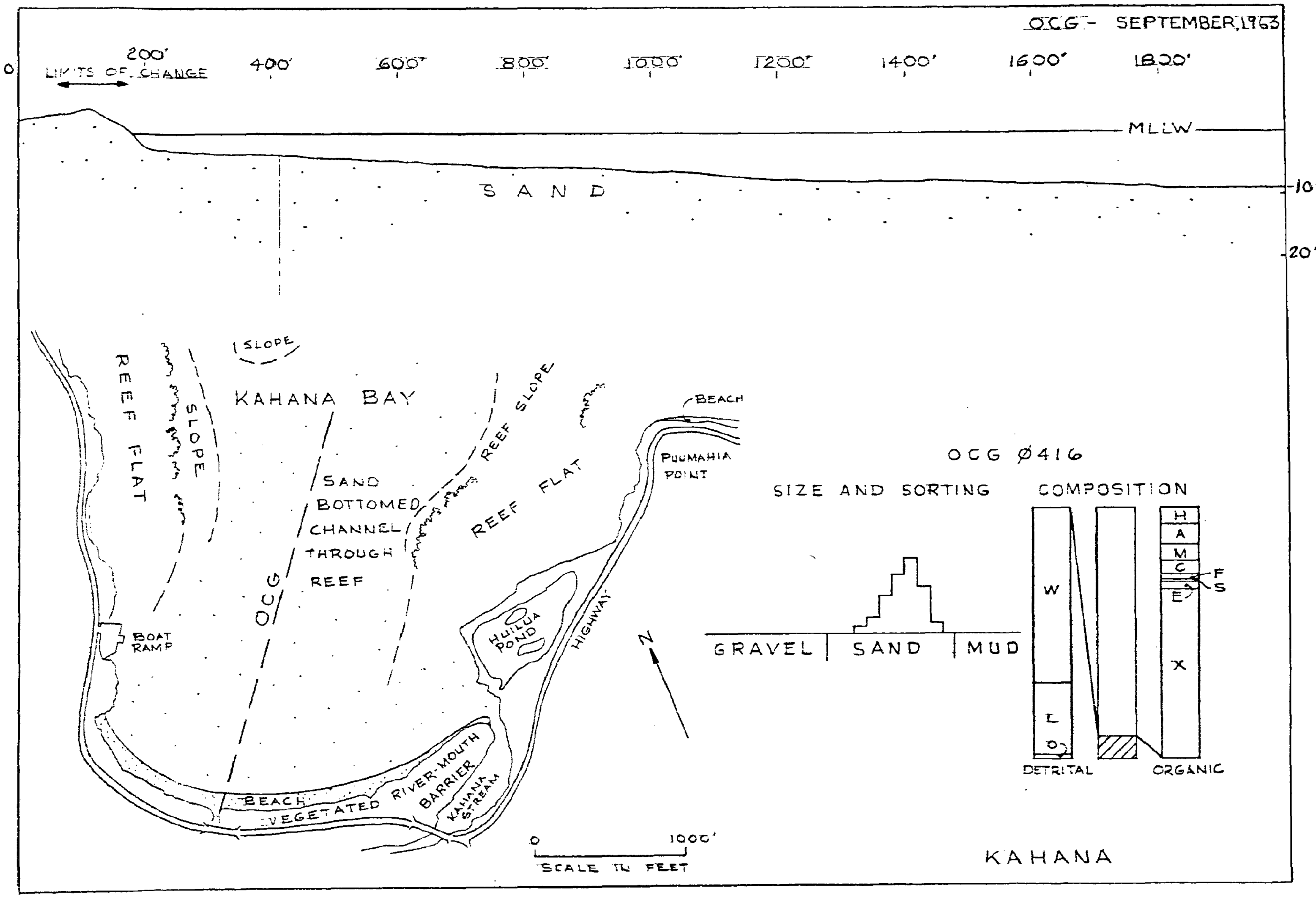
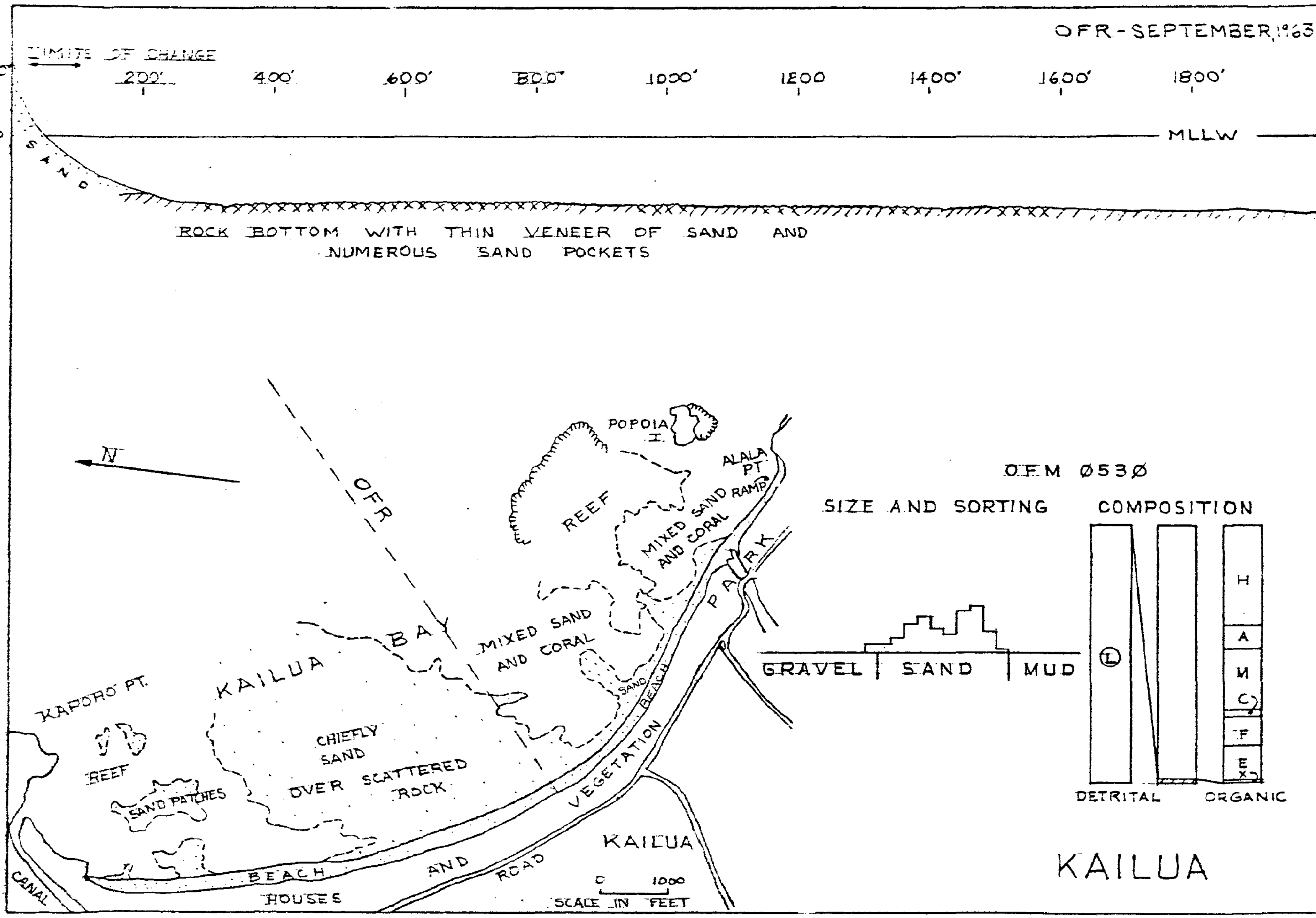

OCG - SEPTEMBER, 1963
0
200'
LIMITS OF CHANGE
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
SAND
10'
20'
SLOPE
REEF FLAT
SLOPE
KAHANA BAY
SAND
BOTTOMED
CHANNEL
THROUGH
REEF
OCG
REEF SLOPE
REEF FLAT
BEACH
PUUMAHIA
POINT
BOAT
RAMP
HUILUA
POND
HIGHWAY
N
BEACH
VEGETATED RIVER-MOUTH
BARRIER
KAHANA
STREAM
0
1000'
SCALE IN FEET
OCG Ø416
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
DETRITAL
H
A
M
C
F
S
E
X
ORGANIC
KAHANA

Fig. 41



OFR-SEPTEMBER, 1963
LIMITS OF CHANGE
200'
400'
600'
800'
1000'
1200
1400'
1600'
1800'
MLLW
0
10'
SAND
ROCK BOTTOM WITH THIN VENEER OF SAND AND NUMEROUS SAND POCKETS
N
OFR
POPOIA I.
ALALA PT
REEF
MIXED SAND AND CORAL
SAND RAMP
PARK
BAY
MIXED SAND AND CORAL
SAND
BEACH
KAILUA
KAPORO PT.
REEF
CHIEFLY SAND OVER SCATTERED ROCK
SAND PATCHES
VEGETATION
BEACH
HOUSES
AND
ROAD
KAILUA
CANAL
0 1000
SCALE IN FEET
OFM 0530
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
L
H
A
M
C
F
EX
DETRITAL
ORGANIC
KAILUA

Fig. 42

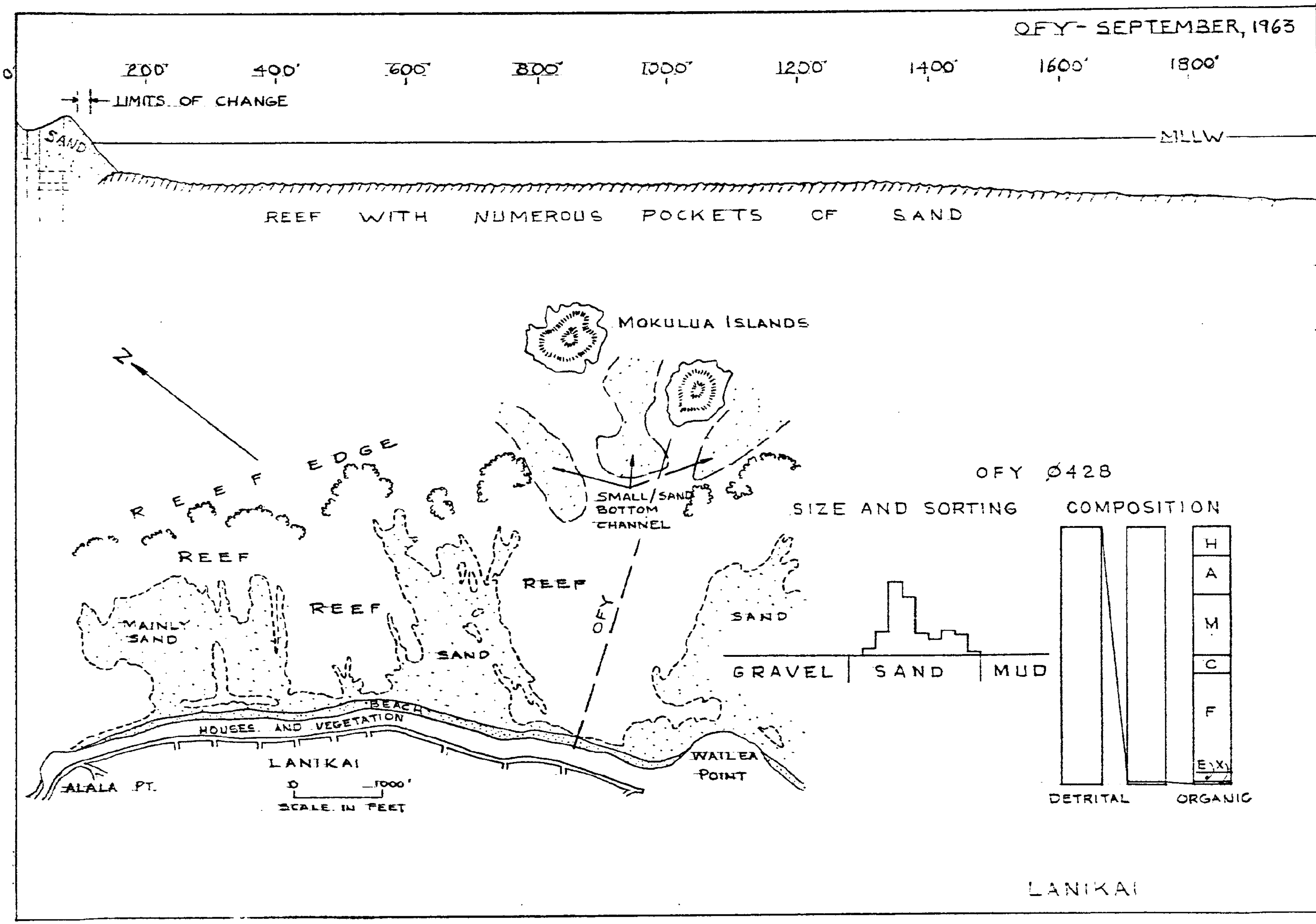

OFY - SEPTEMBER, 1963
+10'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
SAND
MLLW
10'
20'
30'
REEF WITH NUMEROUS POCKETS OF SAND
MOKULUA ISLANDS
N
REEF EDGE
REEF
REEF
REEF
MAINLY SAND
SAND
SAND
SMALL/SAND BOTTOM CHANNEL
OFY
BEACH
HOUSES AND VEGETATION
LANIKAI
ALALA PT.
WAILEA POINT
0
1000'
SCALE IN FEET
OFY Ø428
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
H
A
M
C
F
E
X
DETRITAL
ORGANIC
LANIKAI

Fig. 43

at the southeast end for the past 7 years. Residents report that a reverse drift was true before 7 years ago. Much of this beach is protected by structures such as sea walls and small jetties, and some of these have been washed out.

There is a large reef-flat offshore that is shallower, on the average, than Kailua to the north and Waimanalo to the south. The reef and the two Mokulua Islands reduce wave action on the beach to a minimum. As a result the beach has a low gradient and the sand is poorly sorted. There is good swimming where the reef is covered by sand.

Waimanalo 0-10. (Figure 44.) Waimanalo Beach is the longest continuous beach on Oahu. It curves gently around Waimanalo Bay for about $3\frac{1}{2}$ miles. It is 140 feet wide in the middle near the edge of Bellows Field, but narrows to about 30 feet in width toward its south end.

Over the period of this study the beach changed only 5 feet horizontally. The foreshore has a low slope and is generally cusped. The thickness of the sand at sea level was 9 feet. The rock layer beneath the sand slopes up under the sand so that at the edge of the dunes the sand is only 8 feet thick.

Behind the beach is a series of low dunes that are covered either with vegetation or with houses.

The calcareous sand is coarse- to medium-grained and varies from well sorted to poorly sorted along the beach. The largest component on the sand is foraminifera.

Like Kailua Bay, the offshore area has large patches of sandy bottom, and the reef area is low and irregular in shape. A broad and indistinct sand-bottomed channel crosses the northern part of the reef. At the southern edge of the beach the reef offshore is very shallow.

Makapuu O-10. (Figure 45.) This is a pocket beach about 1,000 feet long that is held on the south end by a high sea cliff and on the north by a lava point. This beach shows considerable seasonal variation in width; in late fall it is about 175 feet wide, and in spring it is eroded back to 125 feet in width. When the erosion is extreme, rock is exposed along the shore at the ends of the beach.

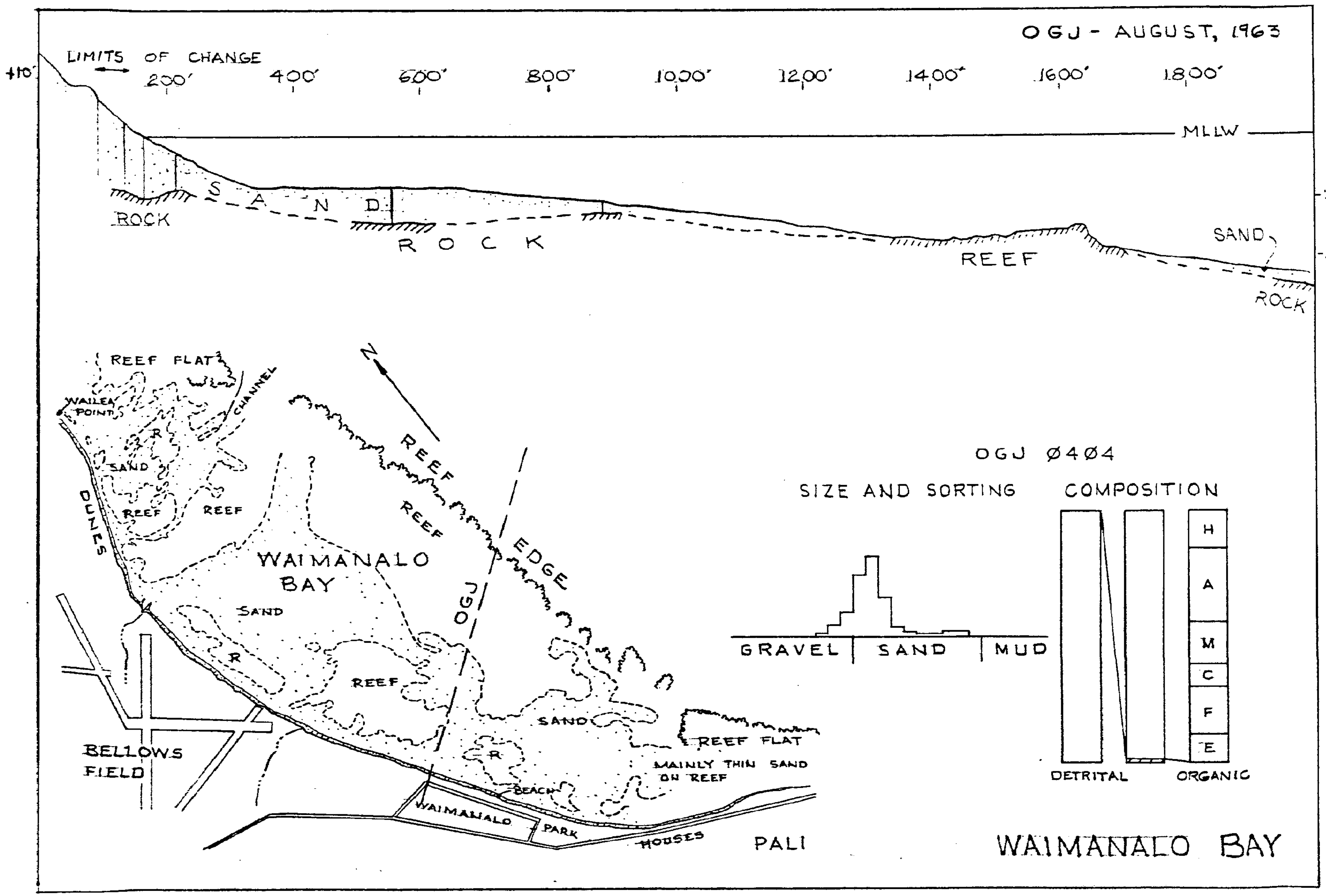
The beach grades coastward into dunes that have blown up against the foot of the pali.

The sand is mostly calcareous, medium-grained, and well sorted.

A large area of sandy bottom offshore appears to be a channel to deep water, but only on a few days were wave conditions sufficiently gentle to allow any close investigation.

Molokai: by F. W. McCoy, Jr.

Kanalukaha (Kapukuwahine) Mo-2. (Figure 46.) Kanalukaha Beach lies immediately east of Kapukuwahine Point on the southern coast of the southwest corner of Molokai. When first visited, the beach was a long, straight beach about 1.8 miles long, and at the range, 150 feet wide. The beach was then marked by large, deep cusps with beachrock exposed in the troughs, except at its western end--this part of the beach was not cusped but instead had a high berm with a moderately steep foreslope. During the winter of 1962, sand-mining operations were begun on this beach and by early spring of the same year the beach



OGJ - AUGUST, 1963
LIMITS OF CHANGE
+10'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
-10'
-20'
SAND
ROCK
ROCK
REEF
SAND
ROCK
REEF FLAT
WAILEA POINT
CHANNEL
SAND
REEF
REEF
DUNES
N
REEF
REEF
EDGE
WAIMANALO BAY
SAND
R
REEF
OGJ
SAND
REEF FLAT
R
MAINLY THIN SAND ON REEF
BEACH
WAIMANALO
PARK
HOUSES
PALI
BELLOWS FIELD
OGJ Ø4Ø4
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
H
A
M
C
F
E
DETRITAL
ORGANIC
WAIMANALO BAY

Fig. 44

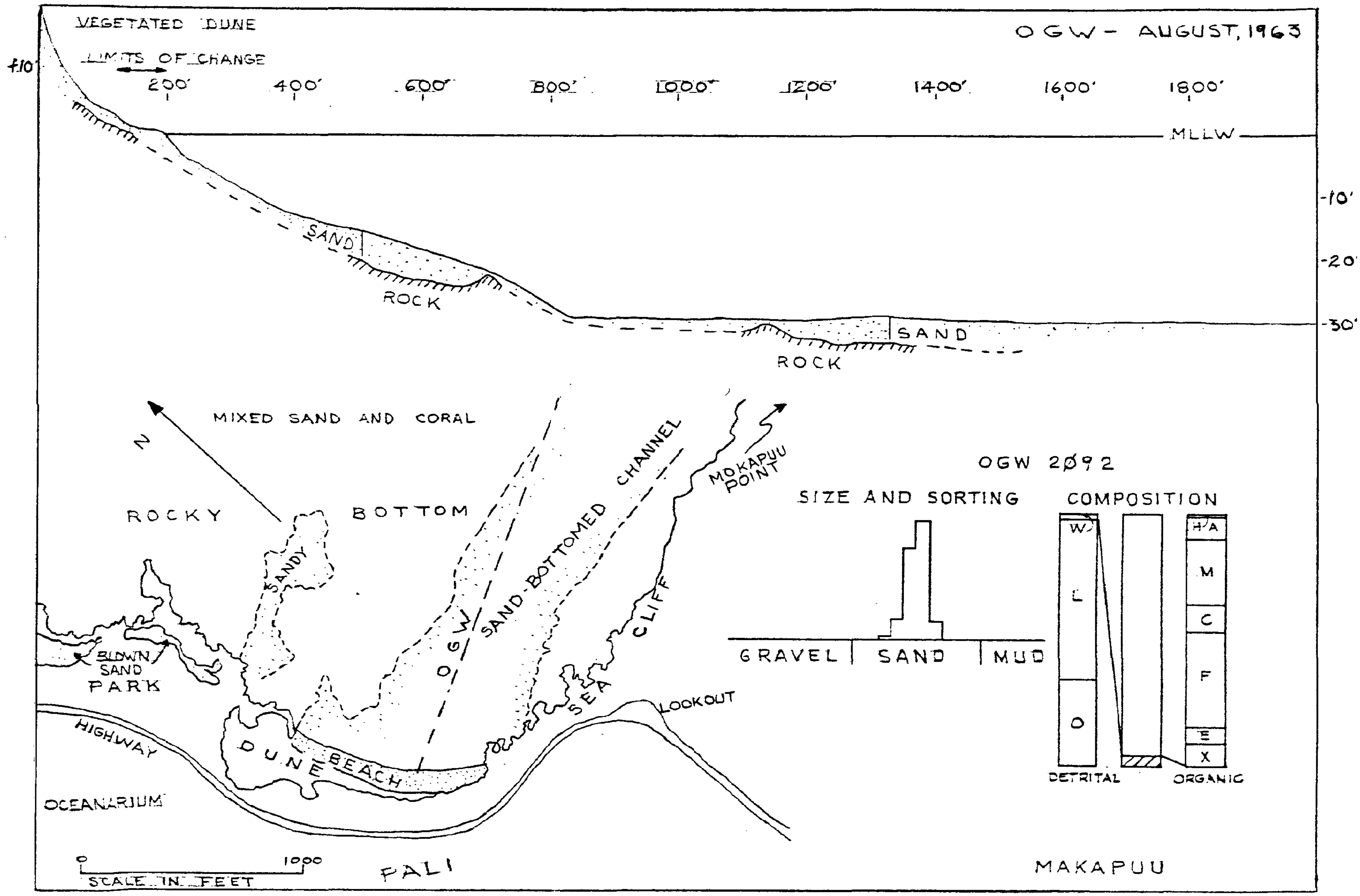
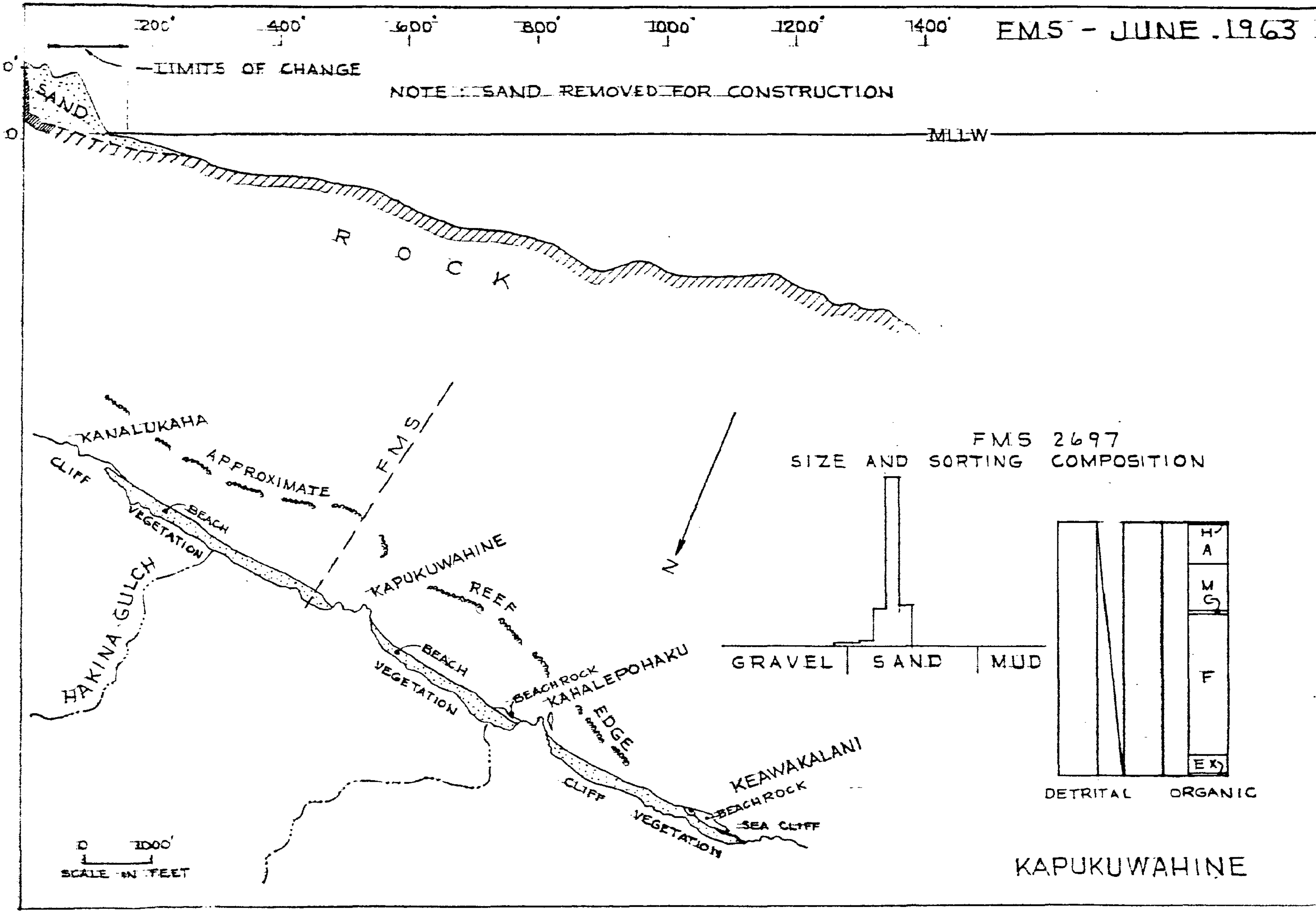

OGW - AUGUST, 1963
VEGETATED DUNE
LIMITS OF CHANGE
+10'
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
-10'
-20'
-30'
SAND
ROCK
SAND
ROCK
MIXED SAND AND CORAL
N
ROCKY
BOTTOM
SANDY
OGW
SAND-BOTTOMED CHANNEL
MOKAPUU POINT
SEA CLIFF
LOOKOUT
BLOWN SAND
PARK
HIGHWAY
DUNE
BEACH
OCEANARIUM
0
1000
SCALE IN FEET
FALI
OGW 2092
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
H A
M
C
F
E
X
DETRITAL
ORGANIC
MAKAPUU

Fig. 45



FMS - JUNE 1963
200'
400'
600'
800'
1000'
1200'
1400'
LIMITS OF CHANGE
NOTE: SAND REMOVED FOR CONSTRUCTION
SAND
MLLW
0'
0
10'
20'
30'
ROCK
KANALUKAHA
APPROXIMATE
FMS
CLIFF
BEACH
VEGETATION
HAKINA GULCH
KAPUKUWAHINE
REEF
BEACH
VEGETATION
BEACHROCK
KAHALEPOHAKU
EDGE
N
CLIFF
VEGETATION
KEAWAKALANI
BEACHROCK
SEA CLIFF
0
1000'
SCALE IN FEET
FMS 2697
SIZE AND SORTING
COMPOSITION
GRAVEL
SAND
MUD
H
A
M
G
F
EX
DETRITAL
ORGANIC
KAPUKUWAHINE

Fig. 46

was completely destroyed. It has since recovered somewhat, but, by early fall of 1963, a small portion of the western end of the beach still remained as jagged beachrock. At that time sand at mean lower low water along the range had thickened to about two feet, and at the berm edge it was 10 feet deep. The backshore is largely a kiawe forest partly covering sand dunes.

The sand is coarse in grain size and is extremely well sorted. It is composed almost entirely of calcareous grains.

Offshore, the bottom is rocky. An alongshore drift towards the west was evident during the fall and early summer. Rip currents occur off the troughs of the cusps. Large plunging breakers were common, with the waves spilling about 200 feet offshore.

Kamakaipo Beach Mo-2. (Figure 47.) Kamakaipo Beach is located along the southern portion of the western coast of Molokai. The sand along this 1-mile length of coastline does not extend to the water, but, rather, it is separated from the ocean by thick beds of beachrock that outcrop throughout the littoral zone. In this respect, Kamakaipo Beach resembles a storm beach. The portion of the beach that was measured periodically was near a slight break in the beachrock. Here the beach is about 120 feet wide, but narrows during late winter. Along the foreslope, the sand thickness averages 2 feet over the beachrock. The backshore is a series of low, vegetated sand dunes which, in turn, are blown over nonconsolidated deposits of sand and silt. The sand is well sorted, very coarse, and very low in volcanic constituents.

Rock, probably beachrock, is exposed offshore. No nearshore currents were evident; waves spilled about 120 feet offshore.

Kaunalu Bay Mo-2. (Figure 48.) Kaunalu Beach is a small pocket beach at the head of Kaunalu Bay, a small bay north of Laau Point. The beach partly bars the mouth of Kaunalu Stream. The beach is about 60 feet wide and 150 feet long, with both ends terminating against boulders lying against the basaltic rock forming the points of the bay. The sand is predominantly of calcareous components, well sorted, and very coarse in size. Some clay is also in the sediment.

Rock is exposed offshore. Circulation within the bay, as shown by the movement of discolored water, is shoreward along both points, and seaward through the central portion of the bay.

North Kaunalu Mo-2. (Figure 49.) An unnamed small beach, here named North Kaunalu Beach, one-half mile north of Kaunalu Bay on the west coast of Molokai, was formed as a pocket beach at the head of a small bay. The beach partly bars an unnamed intermittent stream. It is 250 feet long and 80 feet wide. A berm forms only across the stream at the beach; otherwise the foreslope rises inland with a steady slope to the grassy, flat backshore area. The sand contains a small amount of volcanic material that is largely weathered lava fragments and mud mixed with the predominantly calcareous grains. It is poorly sorted, illustrating a bimodal distribution of fine gravel and very coarse sand.

Sand extends offshore for 800 feet where it laps over rock at the mouth of the bay. Water circulation is shoreward along the south side of the bay and seaward along the north side of the bay. A current trending south off the mouth of the bay completes the circulation cycle.

Papohaku Mo-3. (Figure 50.) Papohaku Beach is a long, straight beach along the west coast of Molokai and lies between a cinder cone at

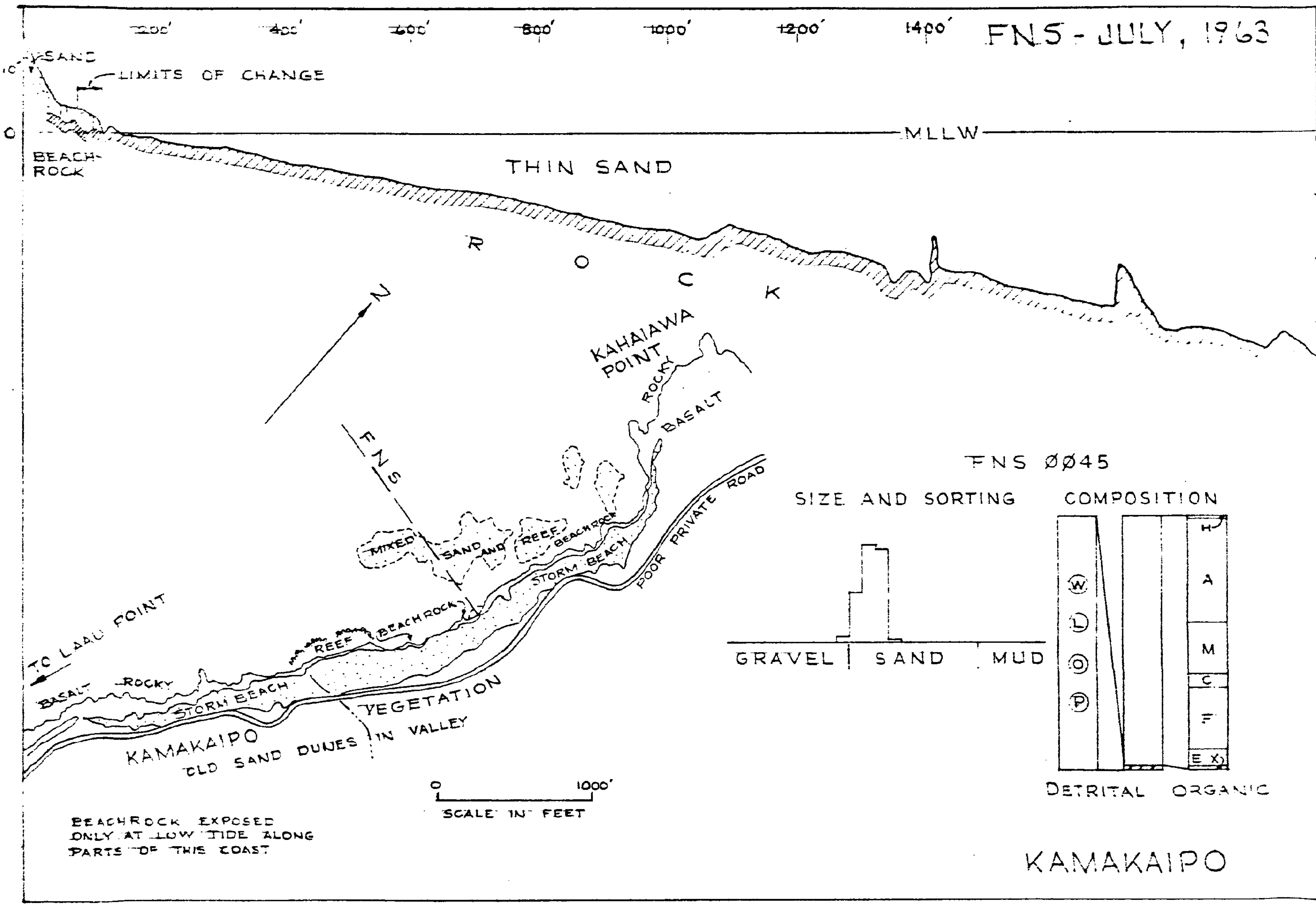
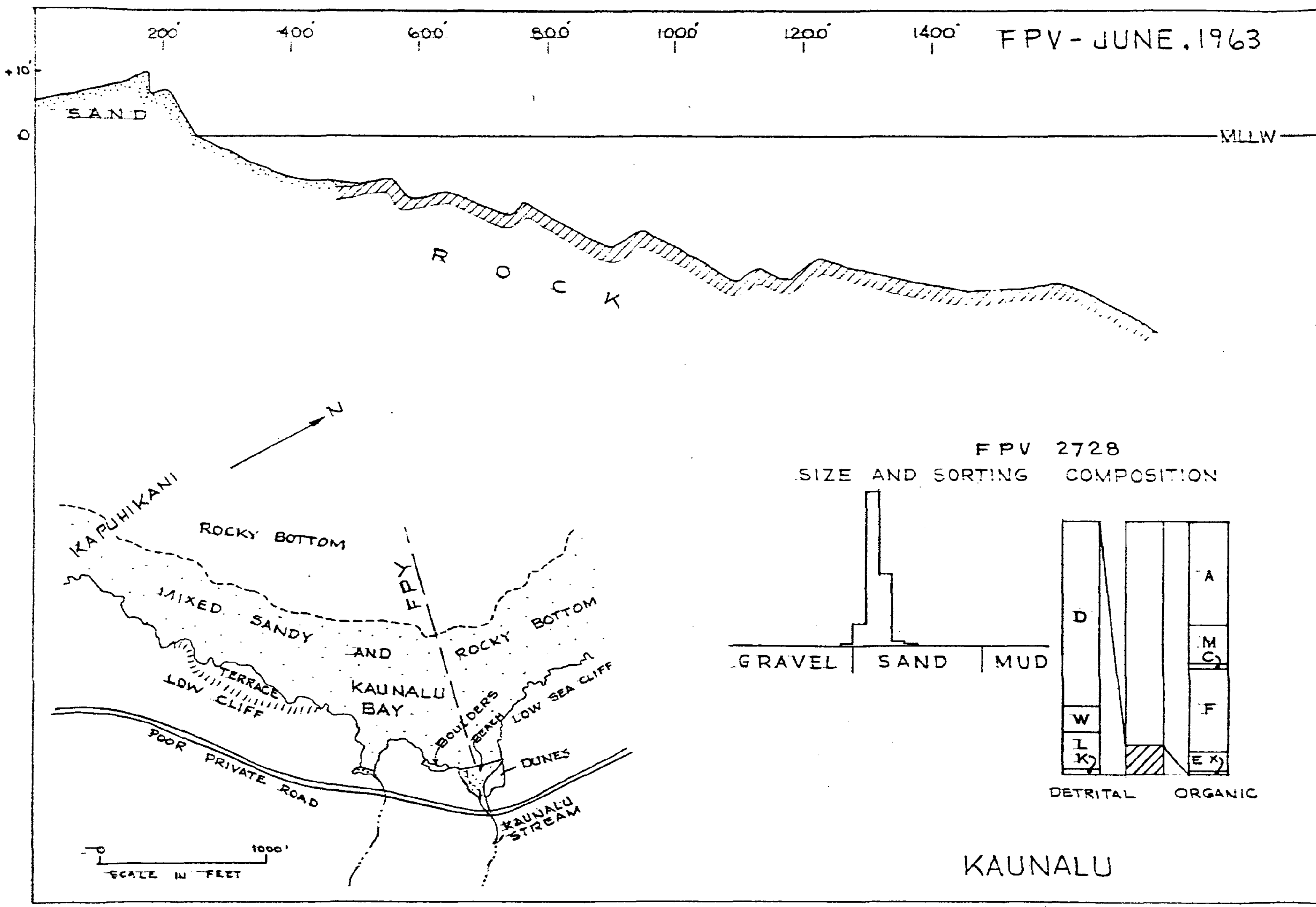
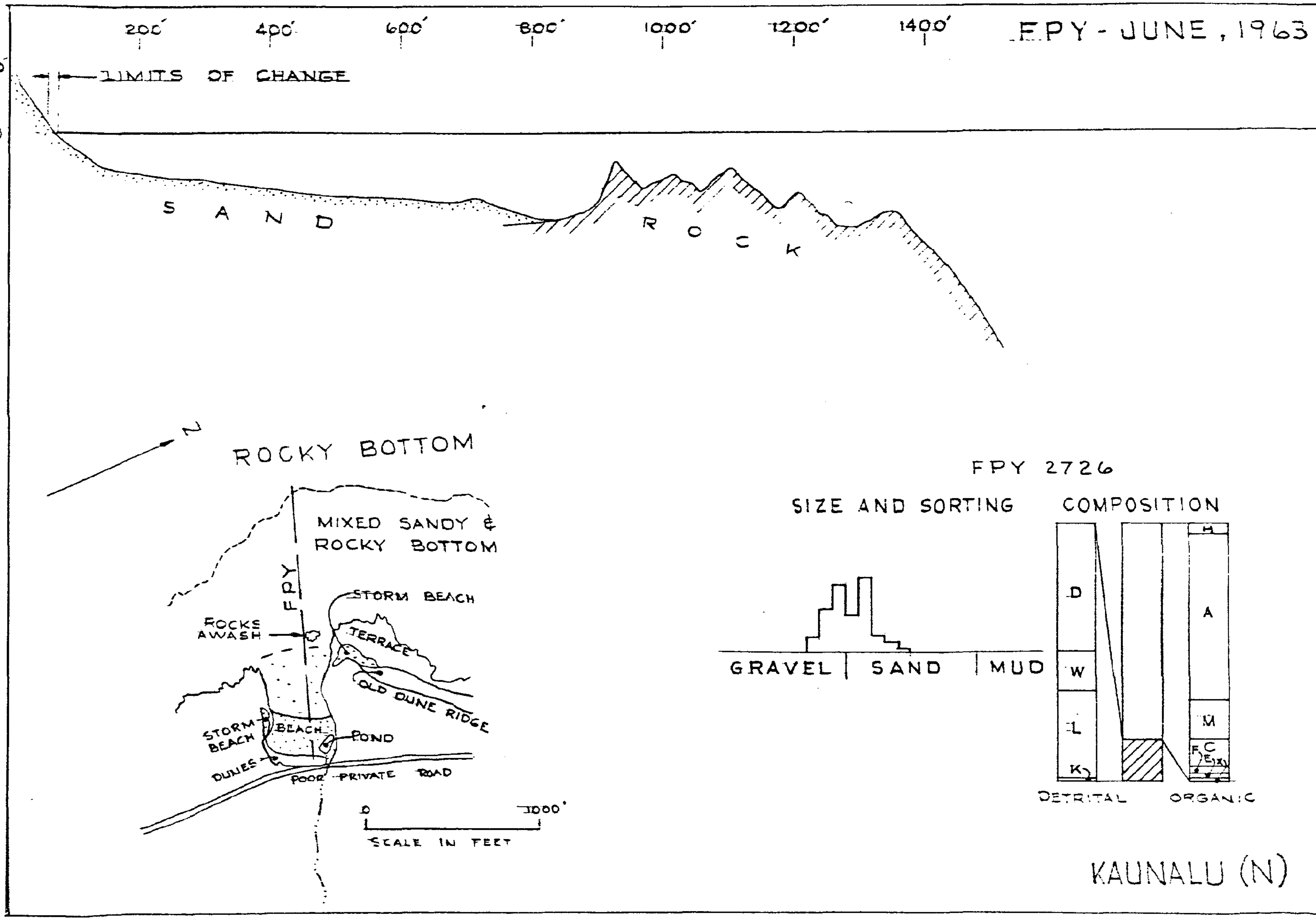

FNS - JULY, 1963
200'
400'
600'
800'
1000'
1200'
1400'
+10
SAND
LIMITS OF CHANGE
0
MLLW
0
BEACH-ROCK
THIN SAND
10'
20'
30'
R O C K
N
FNS
KAHAIAWA POINT
ROCK
BASALT
MIXED SAND AND REEF
BEACHROCK
STORM BEACH
POOR PRIVATE ROAD
BEACHROCK
REEF
TO LAAU POINT
BASALT
ROCKY
STORM BEACH
VEGETATION
KAMAKAIPO
OLD SAND DUNES
IN VALLEY
0
1000'
SCALE IN FEET
BEACHROCK EXPOSED ONLY AT LOW TIDE ALONG PARTS OF THIS COAST
FNS 0045
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
P
H
A
M
C
F
E X
DETRITAL
ORGANIC
KAMAKAIPO

Fig. 47



FPV - JUNE, 1963
200'
400'
600'
800'
1000'
1200'
1400'
+10'
0
SAND
MLLW
0
10'
20'
30'
ROCK
N
KAPUHIKANI
ROCKY BOTTOM
MIXED SANDY AND ROCKY BOTTOM
FPV
KAUNALU BAY
TERRACE
LOW CLIFF
BOULDERS
BEACH
LOW SEA CLIFF
DUNES
POOR PRIVATE ROAD
KAUNALU STREAM
0
1000'
SCALE IN FEET
FPV 2728
SIZE AND SORTING
COMPOSITION
GRAVEL
SAND
MUD
D
W
L
K
A
M
C
F
E
X
DETRITAL
ORGANIC
KAUNALU

Fig. 48



FPY - JUNE, 1963
200'
400'
600'
800'
1000'
1200'
1400'
10'
0
LIMITS OF CHANGE
10
20'
30'
S A N D
R O C K
N
ROCKY BOTTOM
MIXED SANDY &
ROCKY BOTTOM
FPY
STORM BEACH
ROCKS AWASH
TERRACE
OLD DUNE RIDGE
STORM BEACH
BEACH
POND
DUNES
POOR PRIVATE ROAD
0
1000'
SCALE IN FEET
FPY 2726
SIZE AND SORTING
COMPOSITION
GRAVEL
SAND
MUD
D
W
L
K
H
A
M
F
C
E
X
DETRITAL
ORGANIC
KAUNALU (N)

Fig. 49

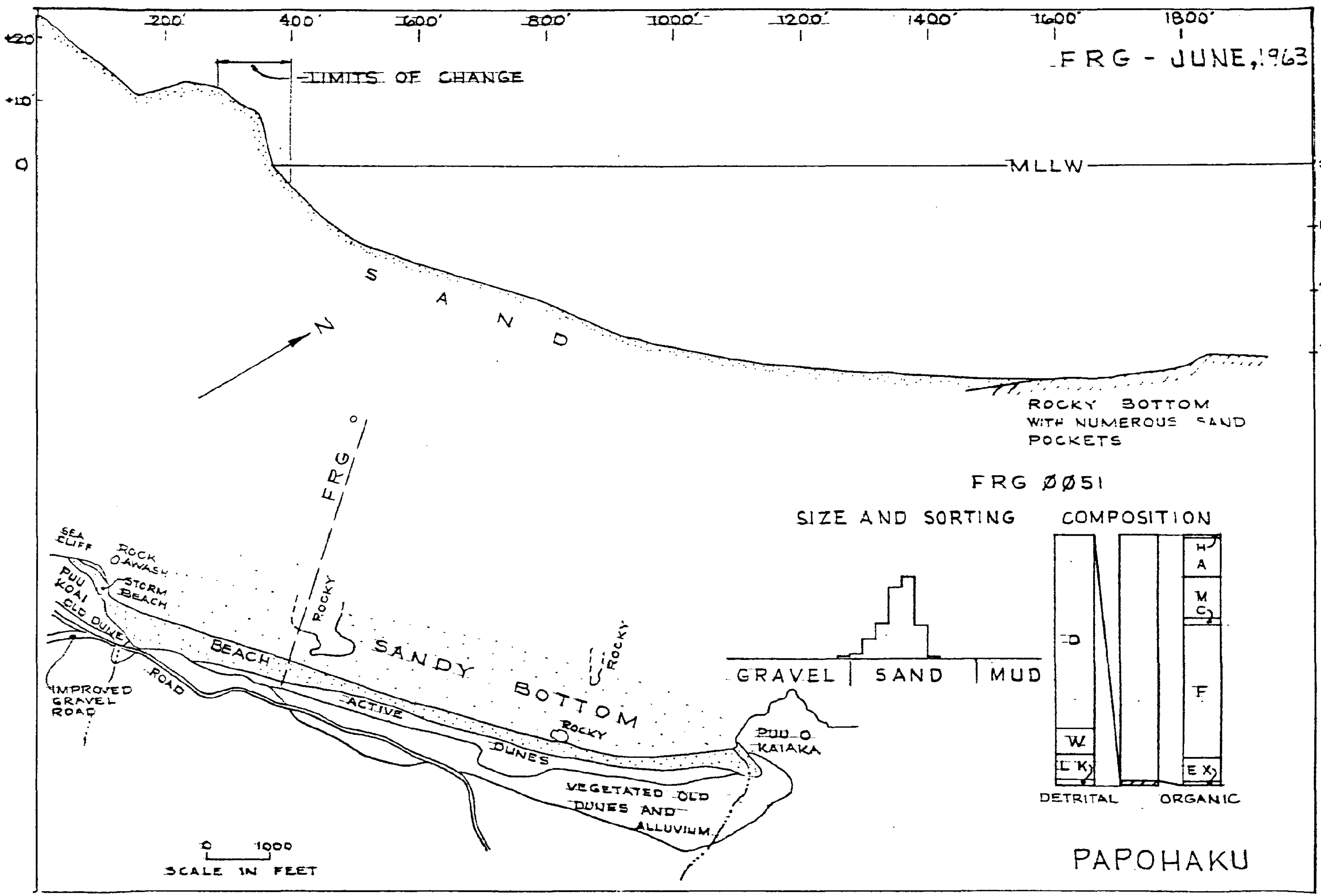

FRG - JUNE, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+20'
+10'
0
10'
20'
30'
LIMITS OF CHANGE
MLLW
SAND
N
ROCKY BOTTOM WITH NUMEROUS SAND POCKETS
FRG ØØ51
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
DETRITAL
ORGANIC
PAPOHAKU
FRG
SEA CLIFF
ROCK O'AWASH
STORM BEACH
PUU KOAI
OLD DUNE
IMPROVED GRAVEL ROAD
ROAD
BEACH
ACTIVE
DUNES
ROCKY
SANDY BOTTOM
VEGETATED OLD DUNES AND ALLUVIUM
PUU O KAIAKA
0
1000
SCALE IN FEET

Fig. 50

the north and a lava point at the south. It is more than two miles long, and along the southern half its width from dune edge to shoreline increases from about 280 feet in early spring to almost 400 feet during late summer. The hinterland is privately owned, undeveloped land. Papohaku is the finest beach on Molokai and one of the finest in the Islands.

A private construction company maintains a permanent sand-mining operation at the southern end of the beach. The removal of sand is a year-round operation which depends upon a southern littoral drift. However, due to a combination of excessive sand removal and to a winter of successive southern storms during 1962-63 (which produced a northward littoral drift), extreme erosion at the southern end of the beach washed out the quarrying operation. It has since been partly rebuilt, however.

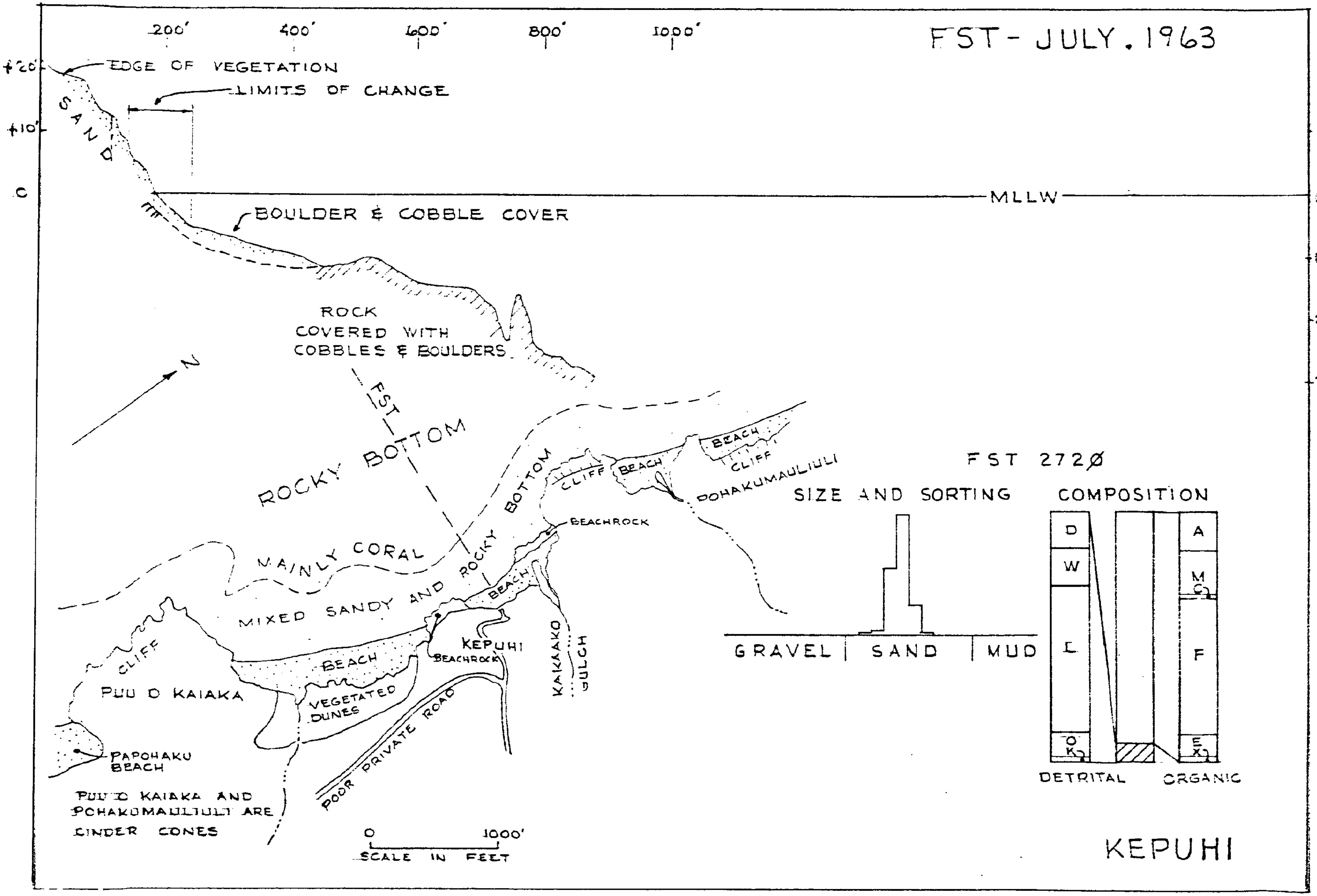
The sand is well sorted, predominantly coarse, and of medium-grain size. There is only a very slight admixture of volcanic components in the predominantly calcareous sand.

Sand extends offshore for more than 1200 feet where it is in contact with rock. Isolated coral heads grow on this hard surface with numerous pockets of sand. Waves usually plunge on the foreshore, producing a steep foreslope. Under tradewind conditions, an alongshore current flows south.

Kepuhi Mo-3. (Figure 51.) The beach at Kepuhi is on the west coast of Molokai, and is separated by a cinder cone at the shoreline from Papohaku Beach farther to the south. Kepuhi Beach is slightly arcuate and 700 feet long. Its width from the edge of the vegetation to the shoreline varied during the period of investigation from 60 feet during early spring to 148 feet during early summer. Kiawe trees predominate on the backshore area with a wide grassy area between the trees and the beach. At both ends the beach is bound by points of volcanic rock, but the cinder cone to the south is partly edged by sand during the period of maximum width, and then Kepuhi Beach becomes almost continuous to Papohaku Beach. In the middle of the beach the thickness of sand at mean lower low water is only 2 feet during the summer. The sand is well sorted and medium-grain size, and contains only a very small proportion of volcanic constituents.

A boulder and cobble bottom exposed offshore also has numerous thin patches of sand. Rock is exposed farther offshore, and is also sporadically covered by cobbles and boulders. A steep foreslope reflects the large plunging breakers which frequent this beach. A northward current has been observed offshore.

Kawaaloa Mo-3. (Figure 52.) Kawaaloa Beach is on the north coast of Molokai, east of Ilio Point, and approximately one mile west of the Hawaiian Homes Commission beach at Moomomi. This beach is more than 1500 feet long, and during early summer it is 125 feet wider than during early winter. In plan view, the beach is crescentic with points of eolianite at either end of the arc. On the foreshore the thickness of sand above rock could not be ascertained. However, because beachrock was exposed in a pond developed at the mouth of the intermittent stream, the sand is probably thin along the backshore. The sand is well sorted, coarse in size, and predominantly composed of calcareous grains. The foreslope is moderately steep and is typically scalloped by large cusps.



FST - JULY, 1963
200'
400'
600'
800'
1000'
+20'
+10'
0
0
10'
20'
30'
EDGE OF VEGETATION
LIMITS OF CHANGE
SAND
MLLW
BOULDER & COBBLE COVER
ROCK COVERED WITH COBBLES & BOULDERS
N
FST
ROCKY BOTTOM
MAINLY CORAL
MIXED SANDY AND ROCKY BOTTOM
CLIFF
BEACH
BEACH
CLIFF
BEACH
CLIFF
POHAKUMAULIULI
BEACHROCK
BEACH
KEPUHI
BEACHROCK
KAKAAKO GULCH
CLIFF
PUU O KAIAKA
BEACH
VEGETATED DUNES
POOR PRIVATE ROAD
PAPOHAKU BEACH
PUU O KAIAKA AND POHAKUMAULIULI ARE CINDER CONES
0
1000'
SCALE IN FEET
FST 272Ø
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
D
W
L
O
K
A
M
C
F
E
X
DETRITAL
ORGANIC
KEPUHI

Fig. 51

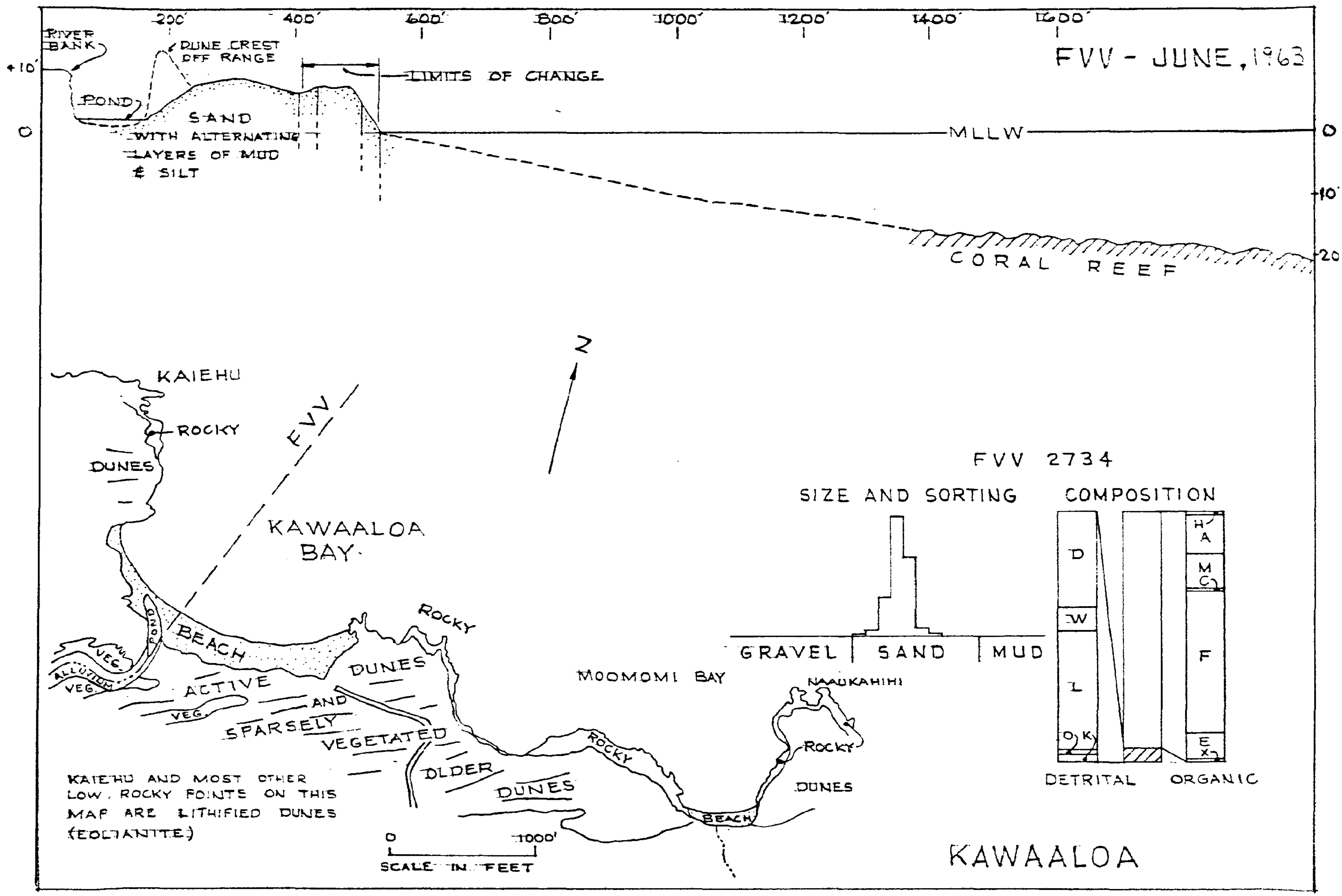

FVV - JUNE, 1963
RIVER BANK
DUNE CREST OFF RANGE
POND
SAND WITH ALTERNATING LAYERS OF MUD & SILT
LIMITS OF CHANGE
MLLW
CORAL REEF
200'
400'
600'
800'
1000'
1200'
1400'
1600'
+10'
0
10'
20
N
KAIEHU
ROCKY
DUNES
FVV
KAWAALOA BAY
BEACH
POND
VEG.
ALLUVIUM
ACTIVE
AND
SPARSELY
VEGETATED
OLDER
DUNES
ROCKY
MOOMOMI BAY
NAAUKAHIHI
BEACH
KAIEHU AND MOST OTHER LOW, ROCKY POINTS ON THIS MAP ARE LITHIFIED DUNES (EOLIANITE)
0
1000'
SCALE IN FEET
FVV 2734
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
D
W
L
O
K
H
A
M
C
F
E
X
DETRITAL
ORGANIC
KAWAALOA

Fig. 52

A coral reef lies about 250 feet offshore. Other offshore data was difficult to obtain due to large breakers and to dirty water throughout most of the period of study.

The backshore is a series of sand dunes built by the brisk tradewinds which sweep almost continuously across this beach. Older dunes, some solidified, extend almost across the island and are known as the Molokai "Desert Strip."

Southwest Kalaupapa Mo-4. (Figure 53.) One of the two large beaches that were investigated at Kalaupapa lies along the western coast of the Kalaupapa Peninsula near its contact with the pali. It is a straight beach, about 3000 feet long, terminating to the west against the talus of boulders at the base of 1600-foot-high sea cliffs and, to the east, against low outcrops of lava. During the summer the beach is 100 feet wide, but, according to local residents, during the winter months it becomes largely a boulder beach because of erosion. The sand is a well-sorted mixture of medium-size grains which are largely volcanic in origin (predominantly lava fragments), giving the beach a black color. The backshore of sand abruptly ends against a boulder talus at the base of the cliff.

There is no reef offshore; rather, a sandy bottom with a steep slope extends off the beach.

Northwest Kalaupapa Mo-4. (Figure 54.) Immediately north of Kalaupapa settlement on Kalaupapa Peninsula is a narrow beach more than 3000 feet long. Depending upon the season the beach is 60 to 90 feet wide. The shoreline is marked by exposures of lava, beachrock, and beach conglomerate. A rocky bottom extends offshore as a reef-flat covered with numerous sand pockets. In contrast to the beach farther to the south (southwest Kalaupapa), this beach is composed of predominantly calcareous sand that is very well sorted and medium-grained in size.

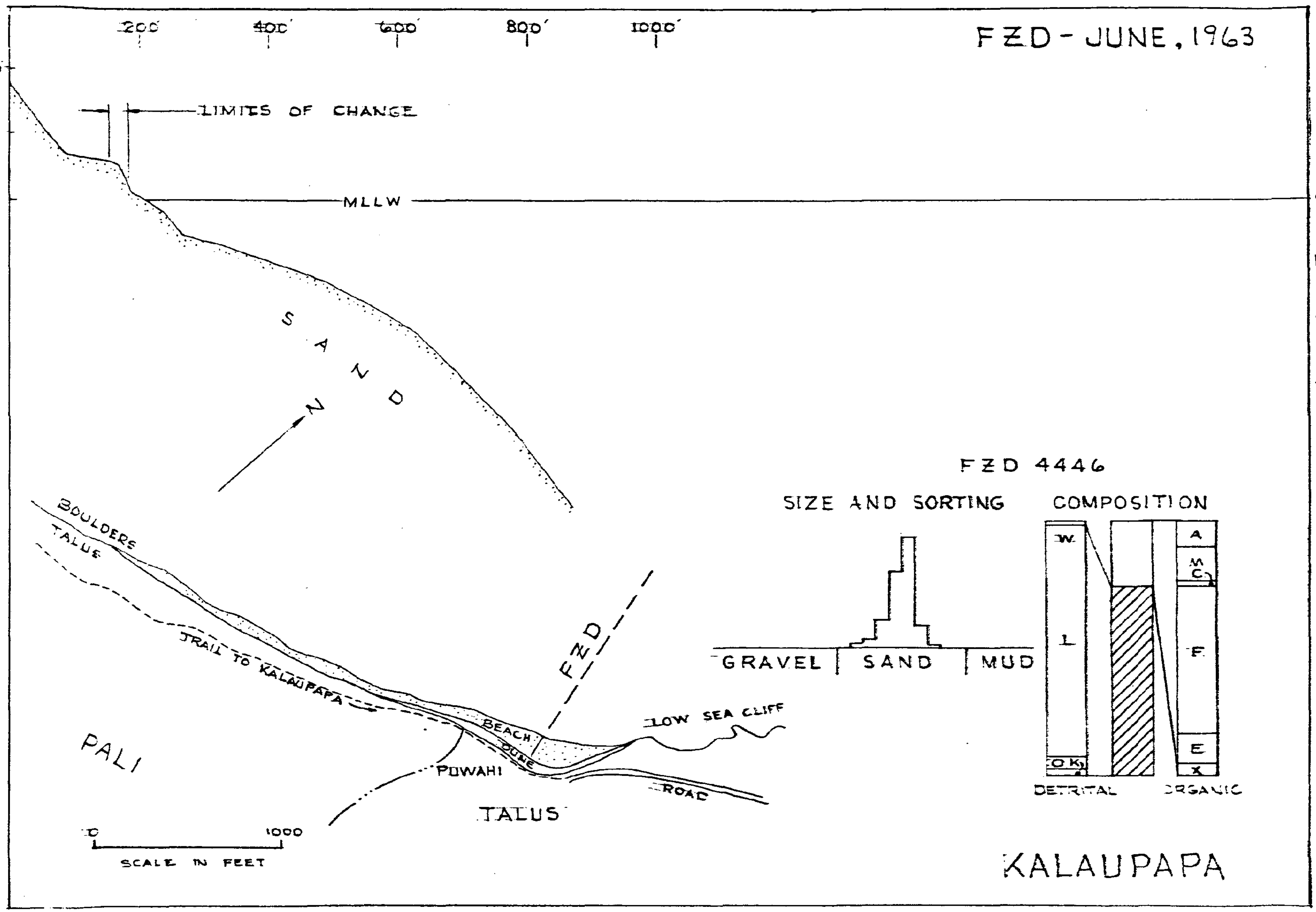
Because the beach lies along the western coast of the peninsula, it is in the lee of local wind waves produced by trades. Thus, except for the winter North Pacific Swell, this beach usually receives only small waves.

Halawa Valley Mo-5. (Figure 55.) At the southeast edge of the mouth of Halawa Valley there is an arcuate pocket beach, terminating, to the east, against a sea cliff cut into the valley wall and, to the west, against a boulder point. This point of boulders also separates the beach from another pocket beach to the northwest at the mouth of Halawa Stream. Throughout the period of investigation the foreshore had a moderate slope with no well-defined berm. The seasonal change during the study was not extreme, the largest change occurring during the early spring.

Offshore, the bottom is rocky, largely covered with boulders out to about a 25-foot depth. At mean lower low water the sand is 5 feet thick over the rocky surface.

The sand is of medium-grain size, well sorted, and composed partly of volcanic fragments (largely weathered lava) and calcareous organic remains in about equal proportions.

The backshore to the east is cut by 6-foot escarpments and numerous gullies. To the west, this escarpment is mantled by low sand dunes which are slowly marching across the surrounding pasture land.



FZD - JUNE, 1963
200'
400'
600'
800'
1000'
+20
+10
0
MLLW
LIMITS OF CHANGE
0
10
20
30
40
50
SAND
N
BOULDERS
TALUS
TRAIL TO KALAUPAPA
BEACH
DUNE
FZD
LOW SEA CLIFF
POWAHI
ROAD
TALUS
PALI
0
1000
SCALE IN FEET
FZD 4446
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
K
A
M
C
F
E
X
DETRITAL
ORGANIC
KALAUPAPA

Fig. 53

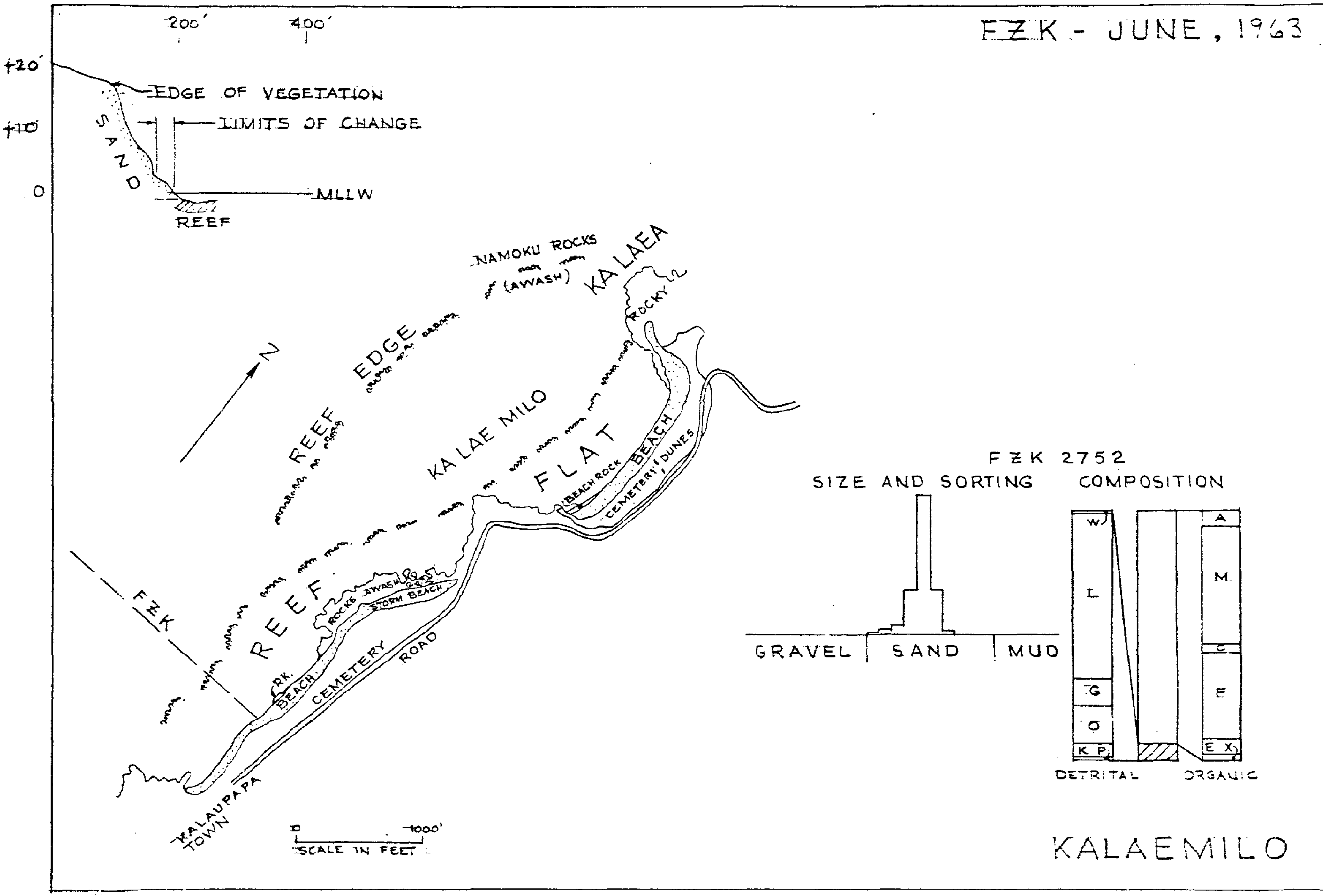

FZK - JUNE, 1963
200'
400'
+20'
+10'
0
EDGE OF VEGETATION
LIMITS OF CHANGE
SAND
MLLW
REEF
NAMOKU ROCKS
(AWASH)
KALAEA
ROCKY
N
REEF EDGE
KA LAE MILO
FLAT
BEACH ROCK
BEACH
CEMETERY DUNES
REEF
ROCKS
AWASH
STORM BEACH
RK.
BEACH
CEMETERY
ROAD
FZK
KALAUPAPA TOWN
0
1000'
SCALE IN FEET
FZK 2752
SIZE AND SORTING
COMPOSITION
GRAVEL
SAND
MUD
W
L
G
O
K
P
A
M
C
E
X
DETRITAL
ORGANIC
KALAEMILO

Fig. 54

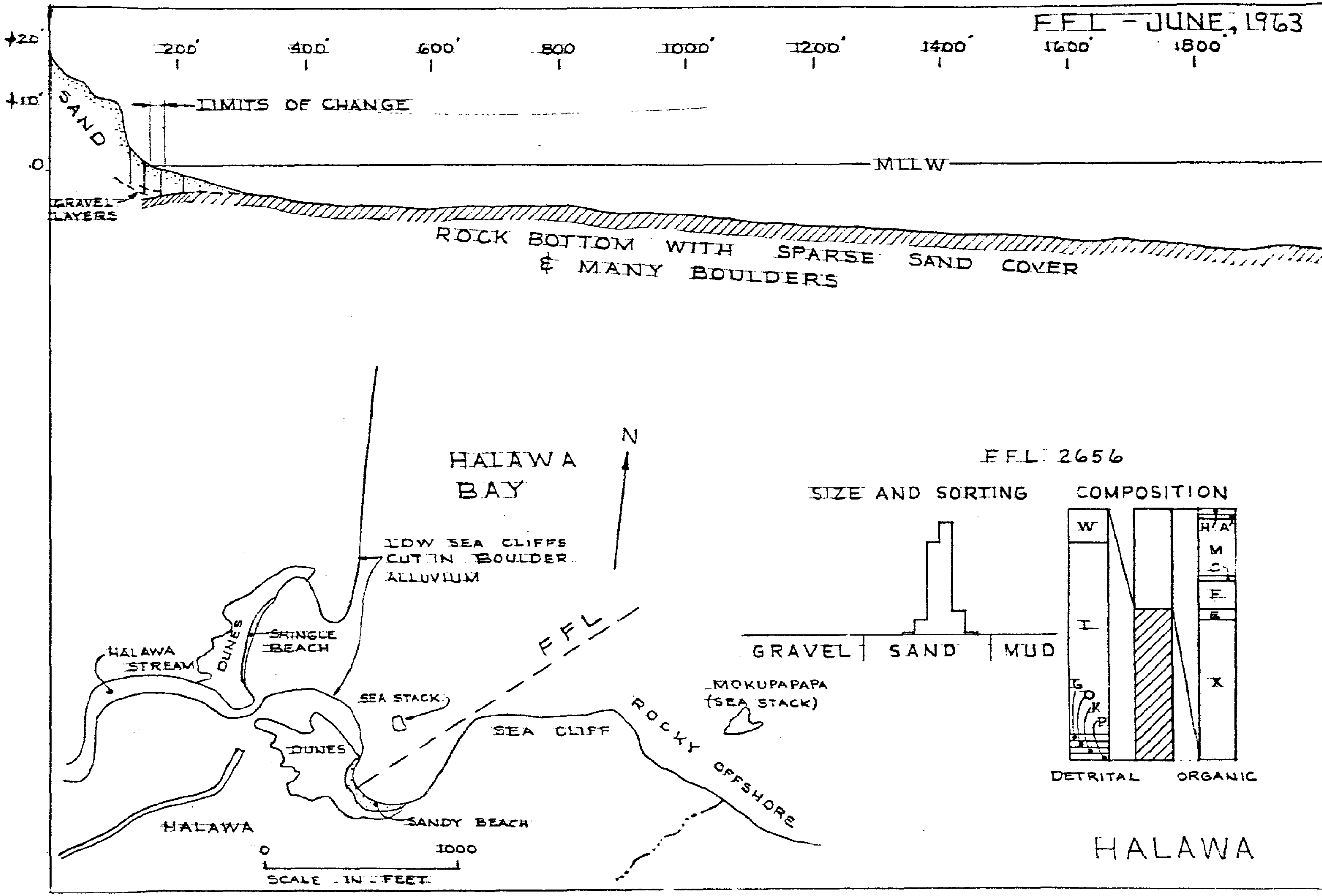

FFL - JUNE, 1963
+20'
+10'
0
200'
400'
600'
800
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
MLLW
SAND
GRAVEL LAYERS
ROCK BOTTOM WITH SPARSE SAND COVER
& MANY BOULDERS
-10'
-20'
HALAWA BAY
N
LOW SEA CLIFFS CUT IN BOULDER ALLUVIUM
SHINGLE BEACH
DUNES
HALAWA STREAM
SEA STACK
FFL
SEA CLIFF
ROCKY OFFSHORE
MOKUPAPAPA (SEA STACK)
DUNES
SANDY BEACH
HALAWA
0
1000
SCALE IN FEET
FFL 2656
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
I
G
O
K
P
H
A
M
C
F
E
X
DETRITAL
ORGANIC
HALAWA

Fig. 55

<u>Kanaha</u> Mo-6. (Figure 56.) Kanaha Beach, a small arcuate pocket beach along Molokai's southeast coast, is about 65 feet wide and 175 feet long. Very little change was recorded during the study; the maximum horizontal change was only 5 feet at mean lower low water where the sand lies only a foot thick above rock. The berm inland from that point, however, covers the rock to a depth of 7 feet. The rocky surface appears about 10 feet offshore as a reef covered with algae, some coral, and sand in scattered pockets. No offshore currents were noticed.

Onshore, the beach is marked by a moderately steep foreslope. The sand is well sorted, coarse in size, and composed predominantly of calcareous fragments. The backshore is marked near the center of the beach by a 3-foot high escarpment cut into alluvial fill. The highway curves around the beach, and highway fill forms the points at either end of the pocket beach.

<u>Lanai</u>: by F. W. McCoy, Jr.

<u>Hulopoe Bay</u> L-1. (Figure 57.) Hulopoe Beach is a 1500-foot-long, arcuate pocket beach, lying at the head of Hulopoe Bay on the south coast of Lanai. Boulders lying against lava points occur at each end of the beach. During winter the beach is eroded back 45 feet, exposing beachrock. The sand is a bimodal mixture of medium and coarse calcareous grains. Low dunes and a beach park occupy the backshore.

Sand lies offshore, and a patch of boulders outcrop between the 5- and 10-foot depths. The foreslope is steep, a result of the large swell arriving at this beach. Berms and cusps are common beach features.

<u>Polihua</u> L-1. (Figure 58.) Polihua Beach lies along the northwesternmost point of Lanai, facing almost due north. It is a large

beach, more than 1.4 miles in length and with varying width. During the late fall, sand shifts to the eastern edge of the beach, whereas in summer it shifts westward. Thus during winter the eastern portion of the beach is built out to widths of over 350 feet, while the opposite end is almost completely eroded away; the reverse is true in summer. West of the beach, two small pocket beaches are held between points of lava. To the east, a narrow beach commences, and continues around the entire east coast of Lanai, with only local interruptions by beachrock or delta muds. Large, high dunes occupy the backshore at the eastern edge of Polihua Beach, but to the west, the beach sand is deposited against lava. The sand is moderately well sorted, medium and coarse in grain size, and contains very little volcanic detritus. Access to the area is along an extremely rough jeep road, impassable during the winter because part of the road is a stream bed.

Sand lies offshore to a 20-foot depth of water. An extremely strong alongshore current sweeps west during late summer. The beach is usually marked by a moderately steep foreslope, a consequence of the large waves which frequently strike this beach. One of the pocket beaches to the west is cut back into a 12-foot escarpment of sand during late summer.

Halulu Gulch L-2. (Figure 59.) This beach lies just northwest of the mouth of Halulu Gulch on the northeast coast of Lanai. It is one segment of a long, 30- to 40-foot wide beach which rims this entire coastline. During spring, the beach is eroded to a 35-foot width exposing beachrock at sea level. At various other times of the year, numerous other outcrops of beachrock are exposed to the northwest and

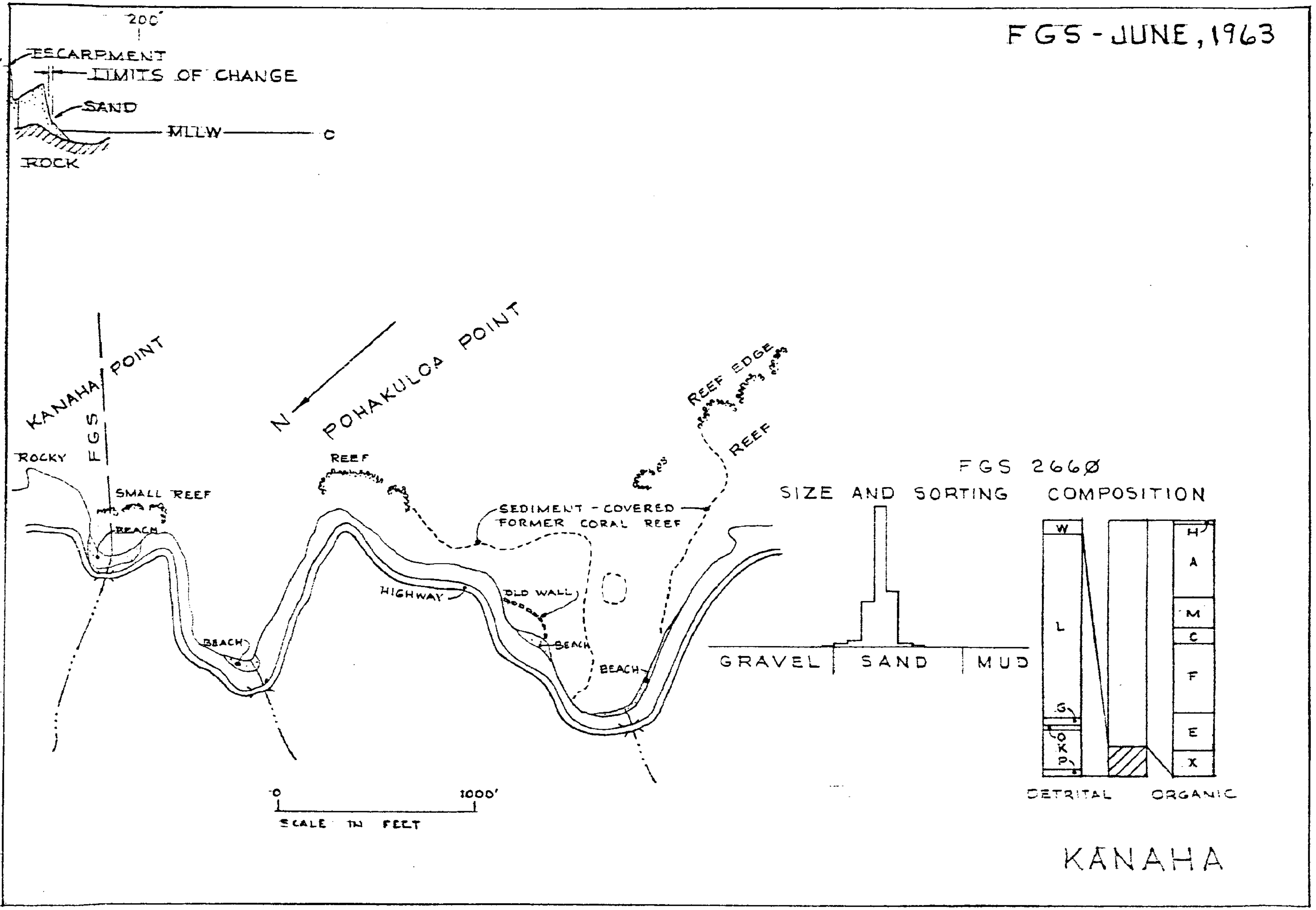
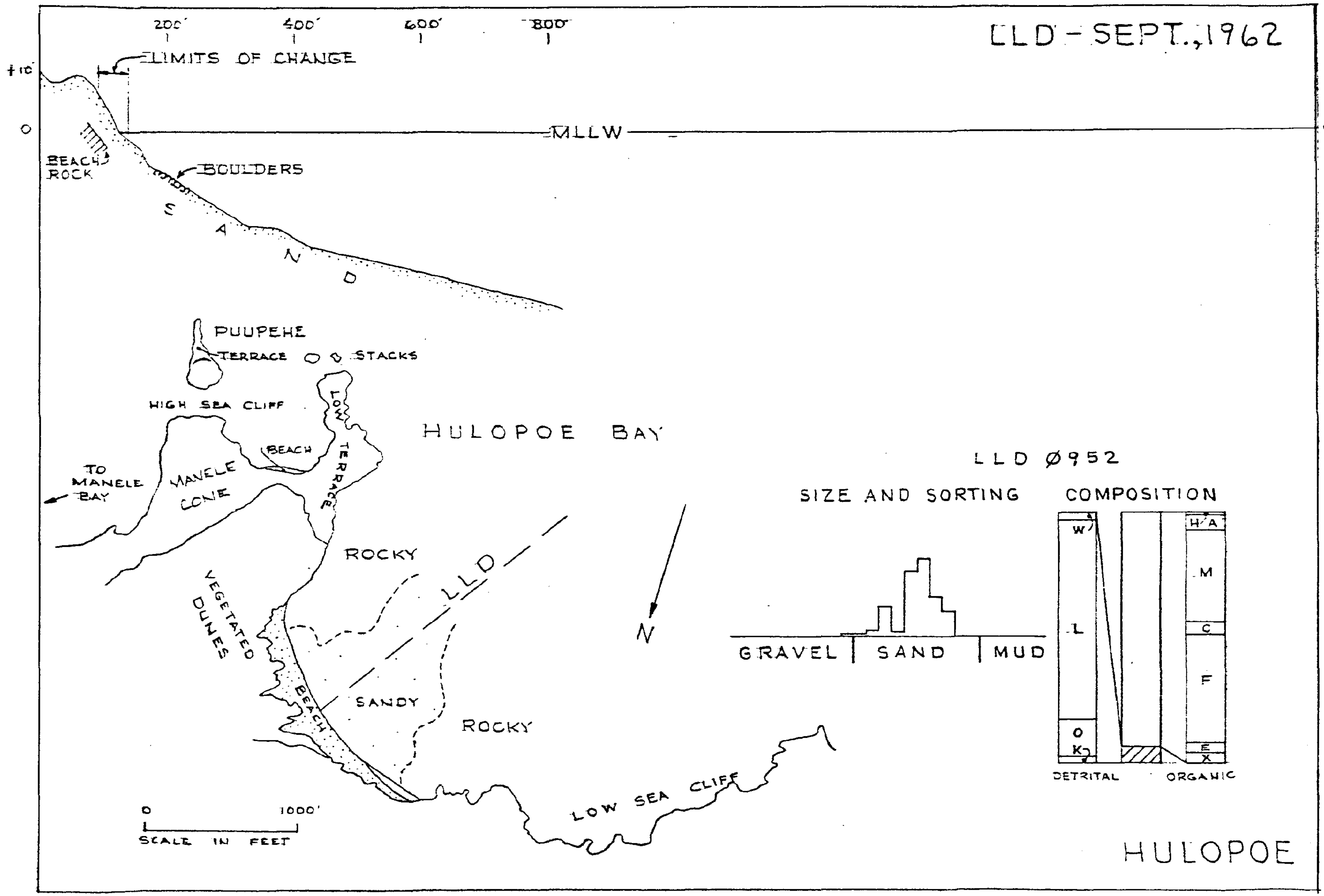

FGS - JUNE, 1963
200'
+10'
0
ESCARPMENT
LIMITS OF CHANGE
SAND
MLLW
C
ROCK
KANAHA POINT
FGS
N
POHAKULOA POINT
ROCKY
SMALL REEF
BEACH
REEF
REEF EDGE
REEF
SEDIMENT - COVERED
FORMER CORAL REEF
HIGHWAY
OLD WALL
BEACH
BEACH
BEACH
0
1000'
SCALE IN FEET
FGS 266Ø
SIZE AND SORTING
COMPOSITION
GRAVEL
SAND
MUD
W
L
G
O
K
P
H
A
M
C
F
E
X
DETRITAL
ORGANIC
KANAHA

Fig. 56



LLD - SEPT., 1962
200'
400'
600'
800'
+10'
0
10'
20'
30'
LIMITS OF CHANGE
MLLW
BEACH ROCK
BOULDERS
SAND
PUUPEHE
TERRACE
STACKS
HIGH SEA CLIFF
LOW TERRACE
BEACH
TO MANELE BAY
MANELE CONE
HULOPOE BAY
ROCKY
VEGETATED DUNES
LLD
BEACH
SANDY
ROCKY
N
LOW SEA CLIFF
0
1000'
SCALE IN FEET
LLD Ø952
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
K
H A
M
C
F
E
X
DETRITAL
ORGANIC
HULOPOE

Fig. 57

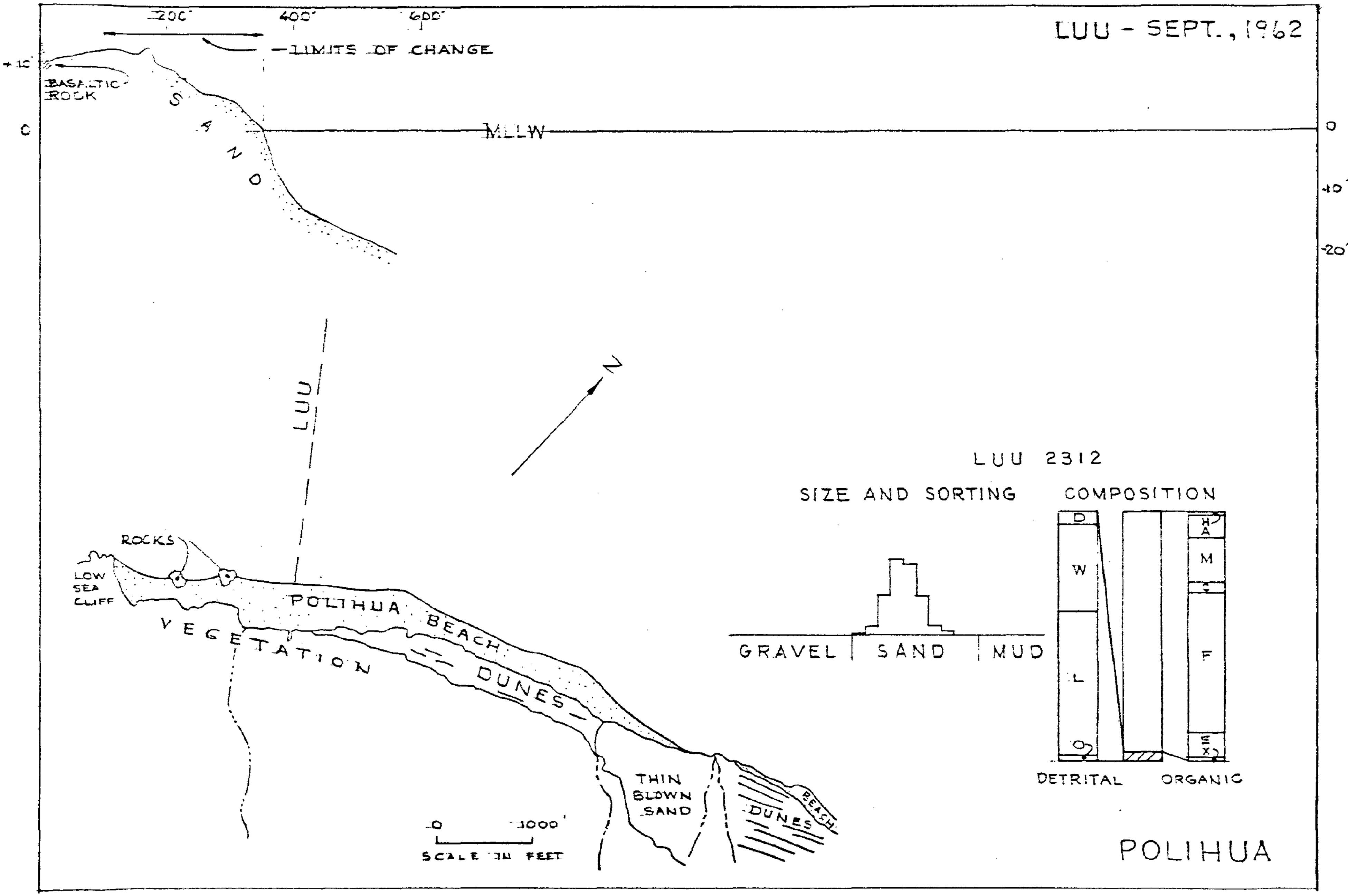

LUU - SEPT., 1962
200'
400'
600'
LIMITS OF CHANGE
+10'
BASALTIC ROCK
0
MLLW
SAND
-10'
-20'
LUU
N
LUU 2312
SIZE AND SORTING
COMPOSITION
GRAVEL
SAND
MUD
D
W
L
M
F
DETRITAL
ORGANIC
ROCKS
LOW SEA CLIFF
POLIHUA BEACH
VEGETATION
DUNES
THIN BLOWN SAND
BEACH
0
1000'
SCALE IN FEET
POLIHUA

Fig. 58

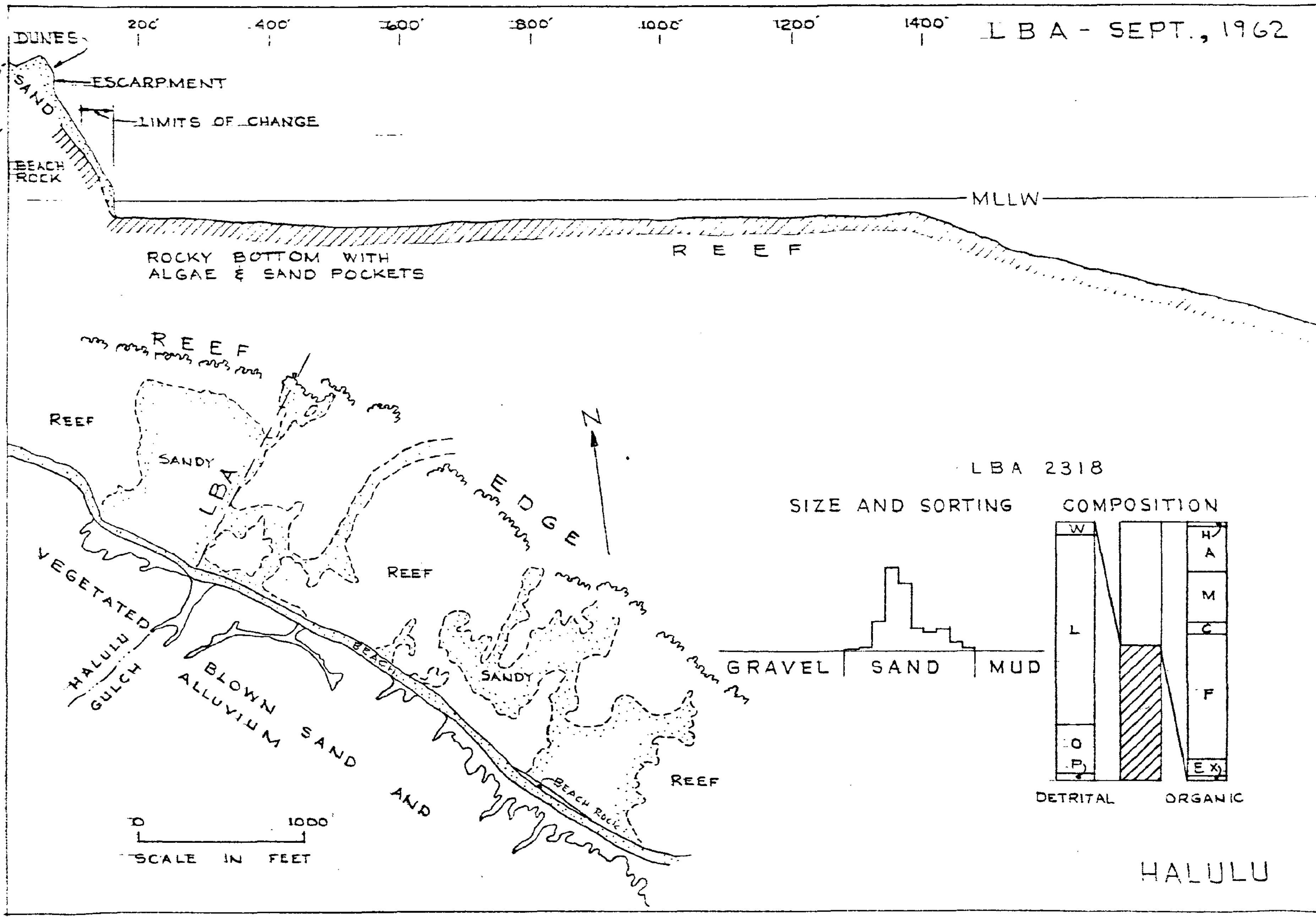

LBA - SEPT., 1962
200'
400'
600'
800'
1000'
1200'
1400'
DUNES
+20'
+10'
0
ESCARPMENT
SAND
LIMITS OF CHANGE
BEACH ROCK
MLLW
0
-10'
-20'
REEF
ROCKY BOTTOM WITH ALGAE & SAND POCKETS
REEF
REEF
SANDY
LBA
N
EDGE
REEF
SANDY
REEF
BEACH
BEACH ROCK
VEGETATED
HALULU GULCH
BLOWN SAND AND ALLUVIUM
0
1000'
SCALE IN FEET
LBA 2318
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
P
H
A
M
C
F
EX
DETRITAL
ORGANIC
HALULU

Fig. 59

southeast, especially where small points of sand protrude. The sand is composed equally of calcareous and volcanic constituents, forming a moderately sorted, medium-sized sediment. The backshore is largely a low-duned area vegetated by kiawe trees and grass.

A rocky reef extends more than 1300 feet offshore, covered mainly with algae, and marked by numerous small pockets of sand and silt. The water offshore is generally muddy during the winter and early spring. An alongshore current to the southeast was noticed. Waves break on the reef edge, and hence can deliver little of their energy to the beach.

Hauola L-2. (Figure 60.) This beach lies on the delta built out by Hauola Gulch on the northeast coast of Lanai, where a continuous alluvial flat has been built out during historical time. The foreshore sediment is a moderately sorted, medium-sized sand, with some gravel, composed almost entirely of olivine and lava fragments, whereas the backshore is a poorly sorted mixture of mud and gravel, intermittently washed seaward by Hauola Stream. Dense kiawe forests and some low sand dunes cover this alluvial flat farther inland. The large change recorded at this beach was due to erosion by the stream during the winter of 1962.

A reef extends offshore for 1300 feet. The sediment on it is similar to that of the backshore; i.e., a poorly sorted mixture of mud, silt, sand, and gravel, with some large boulders. The water covering the reef is muddy, especially following stream discharge. Because waves break offshore on this reef front, only very small waves arrive at the beach.

Maui: by F. W. McCoy, Jr.

Waiehu M-1. (Figure 61.) The beach at Waiehu is one mile north of the mouth of Iao Stream near Kahului Harbor. It is a narrow beach, gently arcuate in shape, and is only 45 feet wide during winter and 30 feet wide during early summer. The sand is well sorted, very coarse in grain size and is composed equally of volcanic and calcareous particles. Vegetated, grassy sand dunes lie between the beach and its marshy hinterland. Sand thickness at mean lower low water is greater than 3 feet; however, beneath the foreshore it is only 3 feet thick.

Waiehu reef extends offshore, with its edge approaching the shore at a boulder beach to the north. Boulders, cobbles, and sand pockets cover the reef surface.

Kahului Harbor M-1. (Figure 62.) A beach 1600 feet long is located within the protected harbor of Kahului. To the east, the beach ends abruptly against a rock fill at Pier 2, whereas to the west it terminates at a rubble beach. During the period of study its width varied by 70 feet, reaching a maximum width of 166 feet in the winter. The predominantly calcareous sand is poorly sorted with grains ranging throughout the sand-size category. The backshore extends to a grassy, sandy area occupied by hotels, houses, and other buildings.

Sand extends offshore for 250 feet, whereupon a rocky bottom covered with algae and barnacles commences. Some sand pockets occur on this surface.

Kahului M-1. (Figure 63.) Immediately east of the eastern Kahului Harbor breakwater is the beginning of a beach that extends more than 5 miles eastward beyond Spreckelsville to Paia. It is a narrow beach,

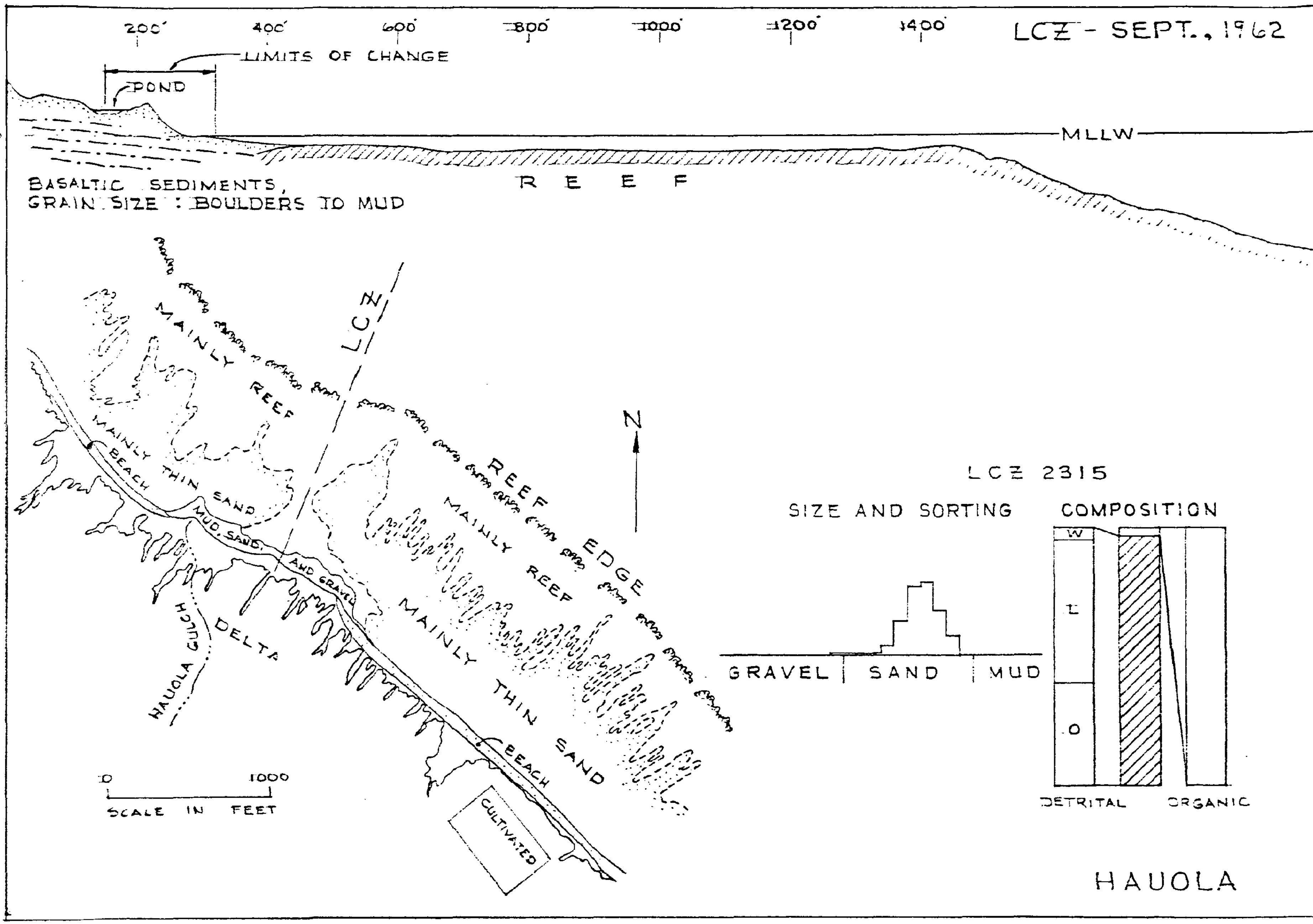

LCZ - SEPT., 1962
200'
400'
600'
800'
1000'
1200'
1400'
+10'
0
10
20'
LIMITS OF CHANGE
POND
MLLW
REEF
BASALTIC SEDIMENTS,
GRAIN SIZE : BOULDERS TO MUD
LCZ
MAINLY REEF
REEF EDGE
MAINLY THIN SAND
BEACH
MUD, SAND
AND GRAVEL
MAINLY REEF
MAINLY THIN SAND
BEACH
CULTIVATED
DELTA
HAUOLA GULCH
N
0
1000
SCALE IN FEET
LCZ 2315
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
DETRITAL
ORGANIC
HAUOLA

Fig. 60

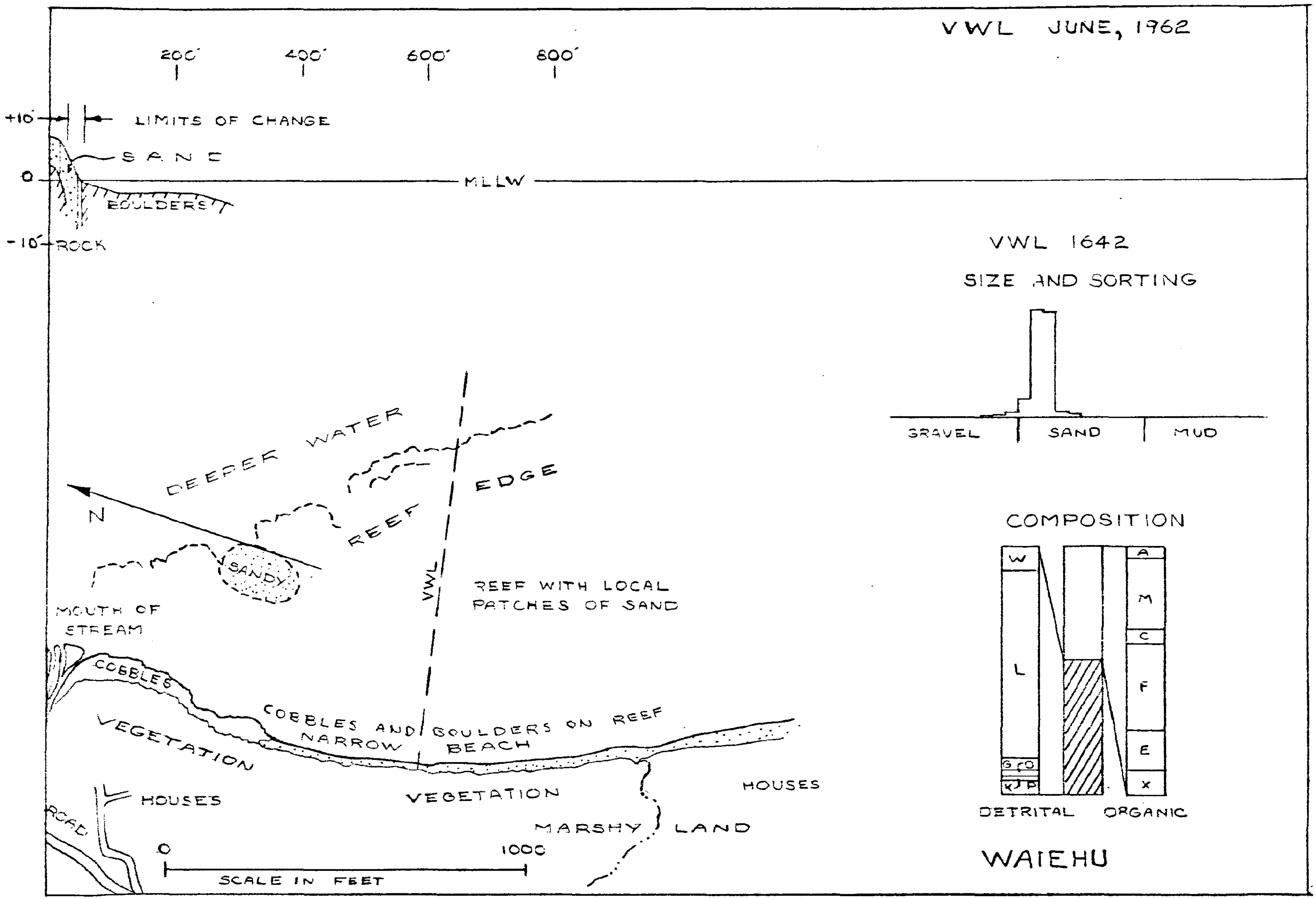

VWL JUNE, 1962
200'
400'
600'
800'
+10'
0
-10'
LIMITS OF CHANGE
SAND
MLLW
BOULDERS
ROCK
VWL 1642
SIZE AND SORTING
GRAVEL
SAND
MUD
DEEPER WATER
REEF
EDGE
N
SANDY
VWL
REEF WITH LOCAL
PATCHES OF SAND
MOUTH OF
STREAM
COBBLES
COBBLES AND BOULDERS ON REEF
NARROW BEACH
VEGETATION
VEGETATION
HOUSES
HOUSES
MARSHY LAND
ROAD
0
1000
SCALE IN FEET
COMPOSITION
W
L
A
M
C
F
E
X
DETRITAL
ORGANIC
WAIEHU

Fig. 61

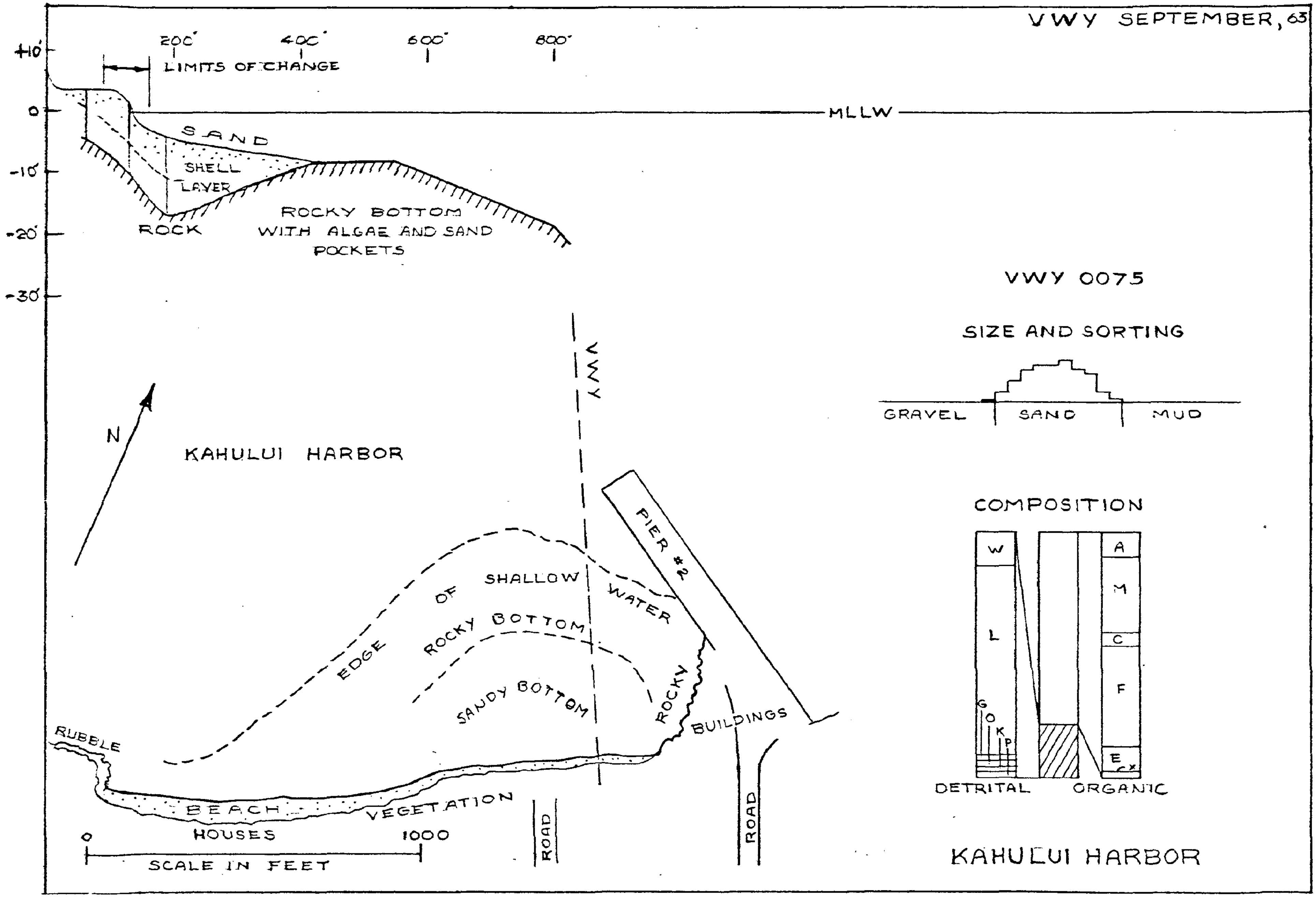
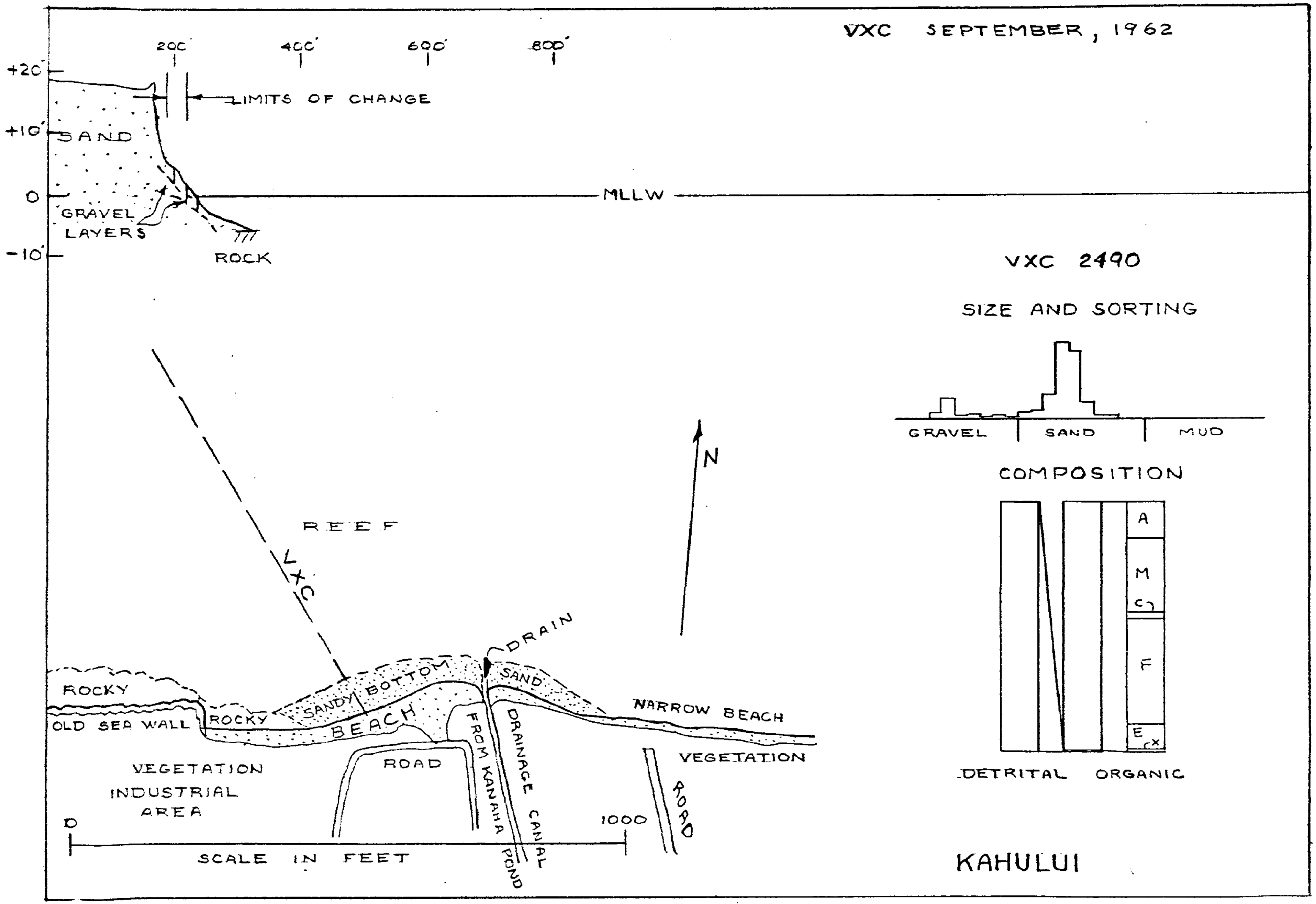

VWY SEPTEMBER, 63
+10'
0
-10'
-20'
-30'
200'
400'
600'
800'
LIMITS OF CHANGE
MLLW
SAND
SHELL
LAYER
ROCK
ROCKY BOTTOM
WITH ALGAE AND SAND
POCKETS
VWY 0075
SIZE AND SORTING
GRAVEL
SAND
MUD
N
KAHULUI HARBOR
VWY
PIER #2
EDGE
OF
SHALLOW
WATER
ROCKY BOTTOM
SANDY BOTTOM
ROCKY
BUILDINGS
RUBBLE
BEACH
VEGETATION
HOUSES
0
1000
SCALE IN FEET
ROAD
ROAD
COMPOSITION
W
L
G
O
K
P
A
M
C
F
E
X
DETRITAL
ORGANIC
KAHULUI HARBOR

Fig. 62



VXC SEPTEMBER, 1962
200'
400'
600'
800'
+20'
+10'
0
-10'
LIMITS OF CHANGE
SAND
MLLW
GRAVEL LAYERS
ROCK
VXC 2490
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
A
M
F
E
DETRITAL
ORGANIC
REEF
VXC
N
DRAIN
SAND
SANDY BOTTOM
BEACH
ROCKY
ROCKY
OLD SEA WALL
NARROW BEACH
VEGETATION
VEGETATION
INDUSTRIAL AREA
ROAD
ROAD
FROM KANAHA POND
DRAINAGE CANAL
0
1000
SCALE IN FEET
KAHULUI

Fig. 63

approximately 40 feet wide, and is interrupted by numerous groins and outcrops of beachrock. The western end of the long beach is presently being used as a sand source for construction purposes and consequently changes often because of mining and stockpiling activities. The sand is poorly sorted, with a bimodal distribution of calcareous grains ranging in size from a cobble-sized coralline gravel to a medium-sized sand. Sand thickness at mean lower low water is greater than 4 feet, though a rocky bottom lies close offshore and continues as a reef which is more than 1300 feet wide. An alongshore current to the west prevails, causing thick masses of seaweed to be deposited on the beach during early summer. However, with southerly storms, an alongshore current to the east is produced.

Spreckelsville M-1. (Figure 64.) The beach near Spreckelsville is part of the long beach discussed as extending from the east breakwater of Kahului Harbor to Paia, along the north coast of central Maui. In the Spreckelsville sector the beach is broken in numerous places by points of lava, boulders, beachrock, and, especially towards the western end, by man-made groins. At Spreckelsville the beach is slightly arcuate with its points being held by beachrock offshore. The beach is about 100 feet wide, and appears to undergo erosion only during the early spring. The beach sand is a poorly-sorted, bimodal mixture of calcareous grains. Large sand dunes, many of which have been excavated or leveled for beach home construction, lie behind the beach.

A reef lies offshore along the entire coast. Live coral predominates along its seaward edge and the back reef is covered by a thin veneer of sand with scattered, large sand pockets.

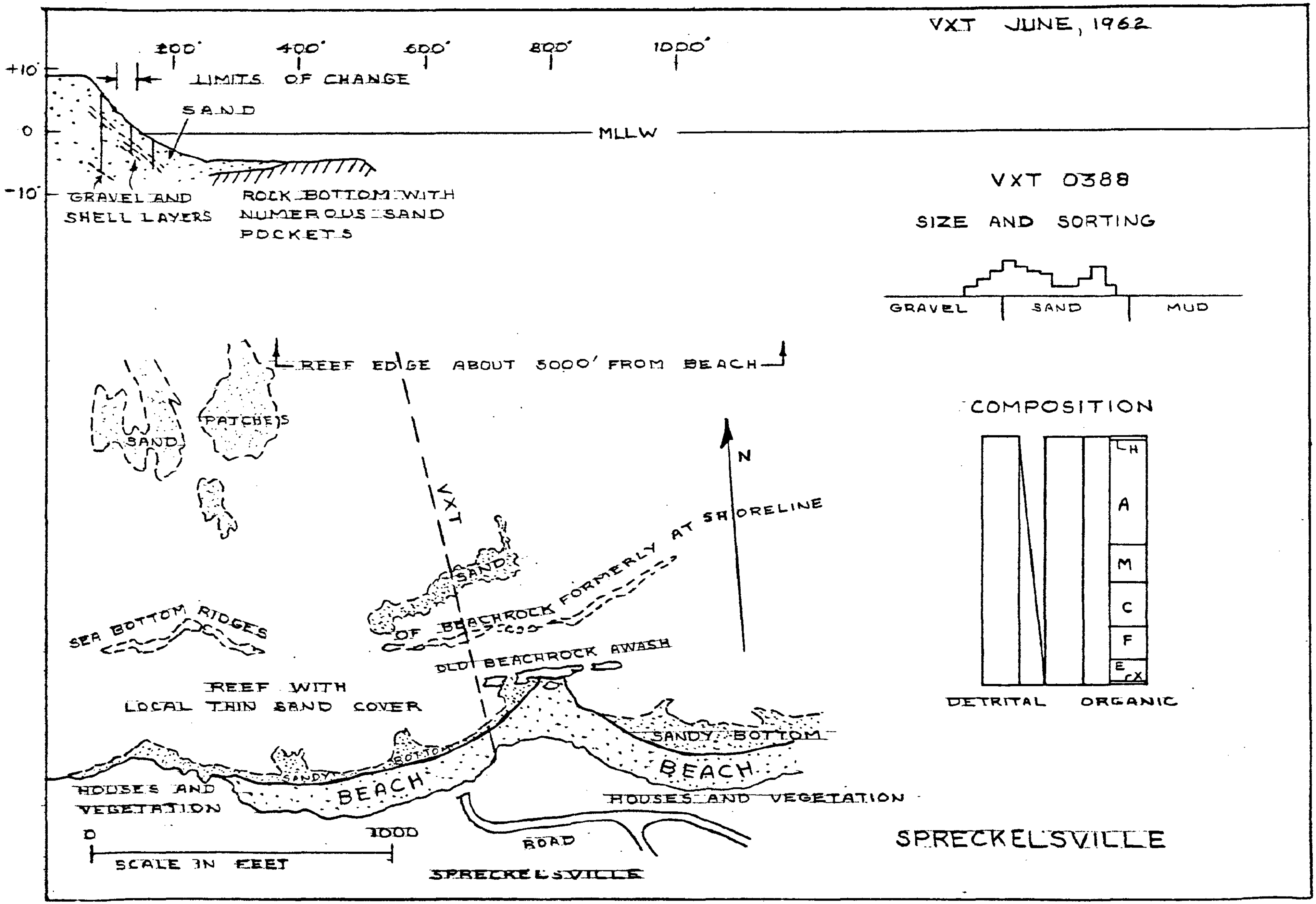
The seriousness of erosion in this area and the need for an intensive specialized study of beach processes there were recognized in a study by F. P. Shepard, K. O. Emery, and D. C. Cox in 1954, and were reported by Cox in a manuscript report for the Hawaiian Sugar Planters' Experiment Station.

Lower Paia M-1. (Figure 65.) This beach forms the eastern terminus of the long narrow beach extending along the north coast of central Maui. Here the beach is slightly arcuate, bound at both ends by lava points. The beach is about 60 to 100 feet wide, with minimum width during the winter. The sand is moderately well sorted, composed almost entirely of fragments of calcareous organisms. The town of Lower Paia occupies the backshore.

Offshore, sand lies on the reef surface in large channels and pockets.

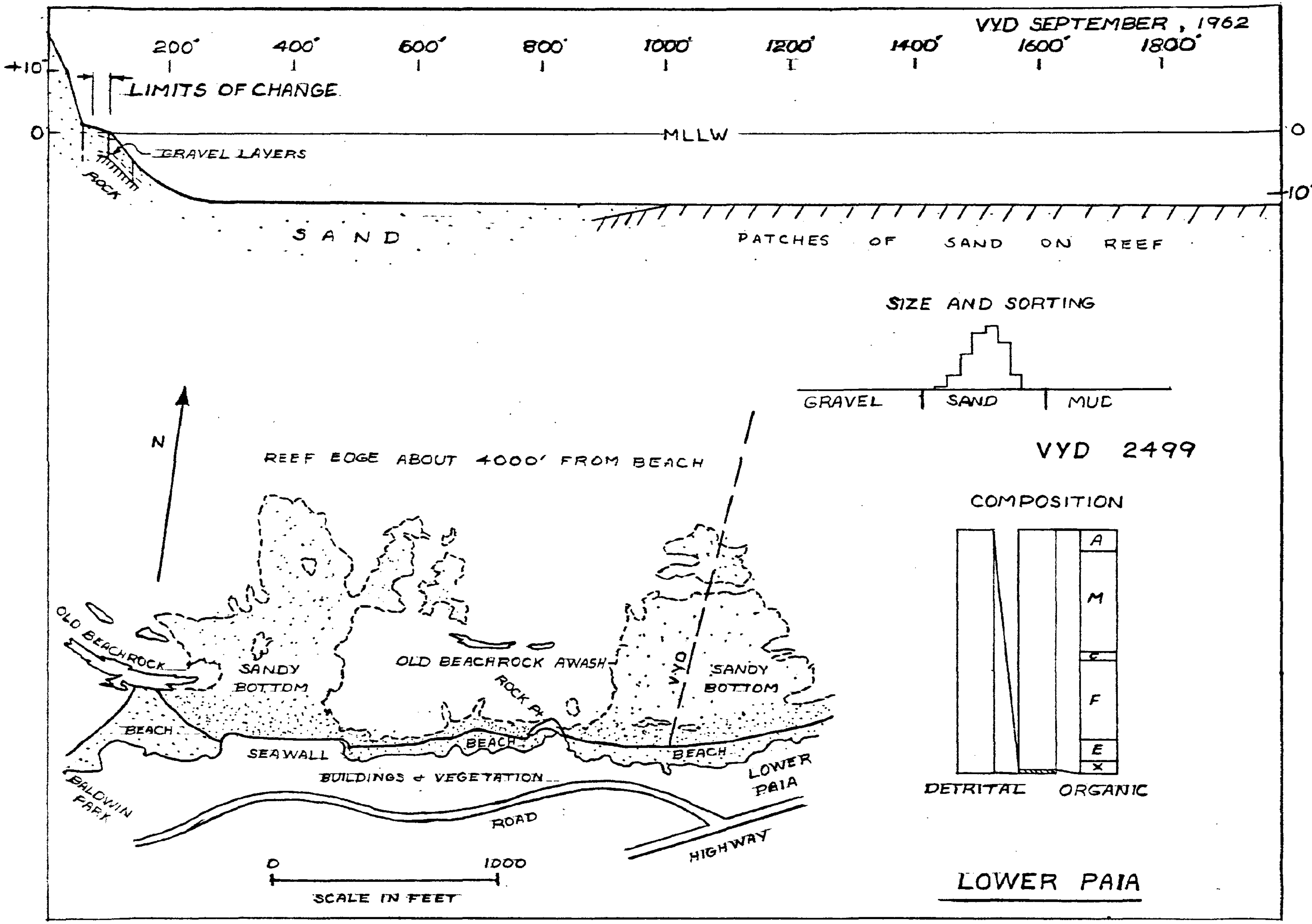
Hana M-3. (Figure 66.) The main beach at Hana lies along the southern shore of Hana Bay, southwest of the pier. Hana beach is arcuate in plan view, 700 feet long and attains a maximum width of 115 feet during the fall. Highway fill to the east and a lava point to the west mark the limits of the beach. The sand is well sorted and fine in size, thus producing a very well compacted foreshore which enables local residents to use the beach as a ramp for launching boats. About three-quarters of the beach sand at Hana is composed of detrital grains of fresh and weathered lava, and one-fourth, of fragments of calcareous organisms. A sea wall separates the backshore from a beach park.

Offshore, the sand continues at a gentle slope to a reef area in the northern part of the bay.



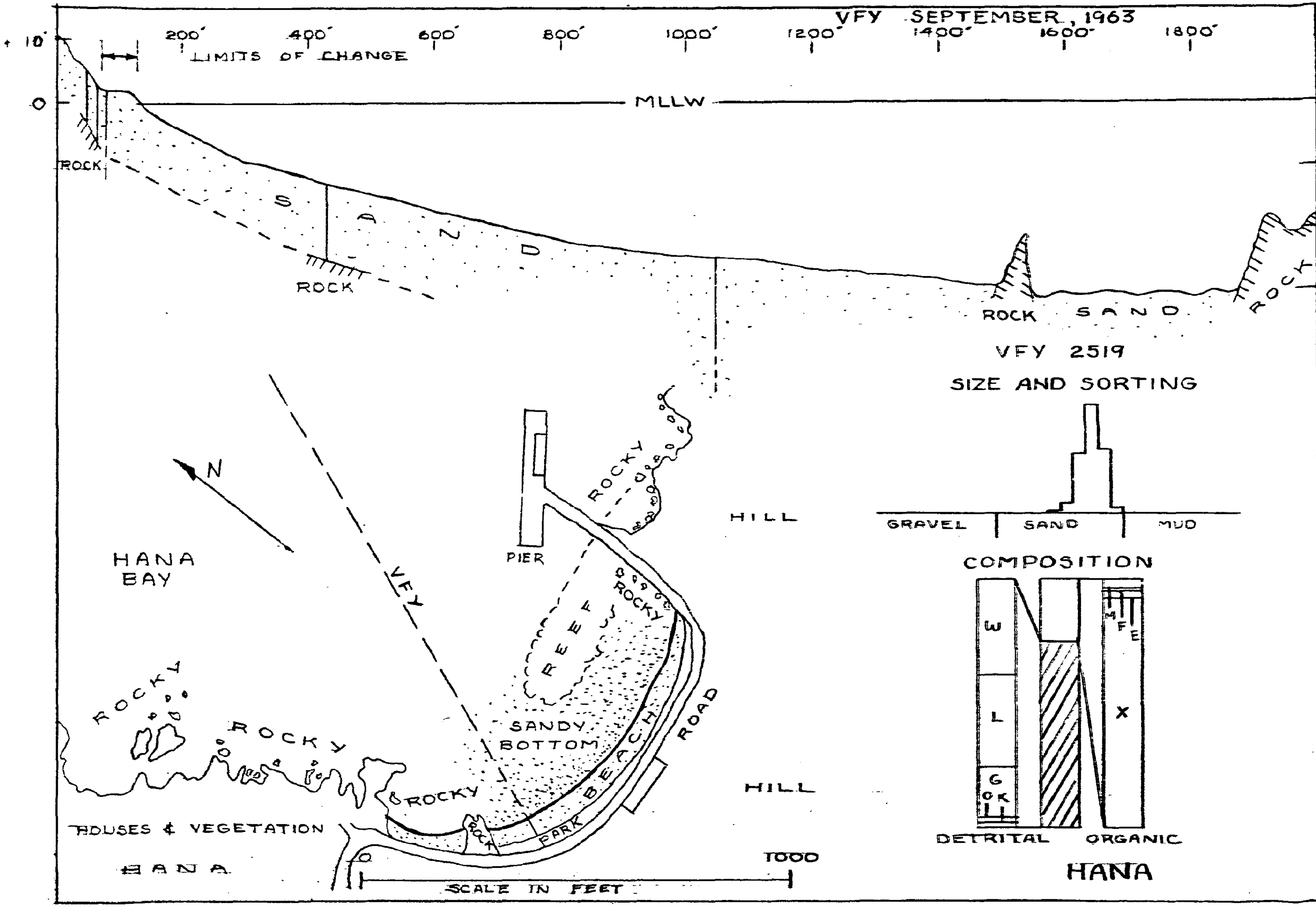
VXT JUNE, 1962
200'
400'
600'
800'
1000'
+10'
0
-10'
LIMITS OF CHANGE
SAND
MLLW
GRAVEL AND SHELL LAYERS
ROCK BOTTOM WITH NUMEROUS SAND POCKETS
VXT 0388
SIZE AND SORTING
GRAVEL
SAND
MUD
REEF EDGE ABOUT 5000' FROM BEACH
SAND
PATCHES
N
VXT
SAND
BEACHROCK FORMERLY AT SHORELINE
OF
OLD BEACHROCK AWASH
SEA BOTTOM RIDGES
REEF WITH LOCAL THIN SAND COVER
SANDY BOTTOM
BEACH
HOUSES AND VEGETATION
ROAD
0
1000
SCALE IN FEET
SPRECKELSVILLE
COMPOSITION
H
A
M
C
F
E
X
DETRITAL
ORGANIC
SPRECKELSVILLE

Fig. 64



VYD SEPTEMBER, 1962
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10
0
-10'
LIMITS OF CHANGE
MLLW
GRAVEL LAYERS
ROCK
SAND
PATCHES OF SAND ON REEF
SIZE AND SORTING
GRAVEL
SAND
MUD
VYD 2499
COMPOSITION
A
M
C
F
E
X
DETRITAL
ORGANIC
N
REEF EDGE ABOUT 4000' FROM BEACH
OLD BEACHROCK
SANDY BOTTOM
OLD BEACHROCK AWASH
ROCK Pt
VYD
SANDY BOTTOM
BEACH
SEAWALL
BEACH
BEACH
BUILDINGS + VEGETATION
LOWER PAIA
BALDWIN PARK
ROAD
HIGHWAY
0
1000
SCALE IN FEET
LOWER PAIA

Fig. 65



VFY SEPTEMBER, 1963
+10'
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
MLLW
0
-10'
-20'
-30'
ROCK
S A N D
ROCK
ROCK
S A N D
ROCK
VFY 2519
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
O K
M
F
E
X
DETRITAL
ORGANIC
HANA
N
HANA
BAY
VFY
PIER
ROCKY
HILL
ROCKY
REEF
ROCKY
ROCKY
SANDY
BOTTOM
BEACH
ROAD
ROCKY
ROCK
PARK
HILL
HOUSES & VEGETATION
HANA
0
1000
SCALE IN FEET

Fig. 66

Hamoa M-4. (Figure 67.) Hamoa Beach lies at the head of Makae Cove, south of Hana, on the eastern tip of East Maui. It is a pocket beach 1000 feet long, with a maximum width of 120 feet during the winter. Cliffs 30 feet high bound the beach at both ends, and curve behind the backshore in a broad arc. Buildings used by a private surf club occupy the backshore. The sand is well sorted, medium and fine in grain size, and is composed largely of calcareous fragments. The sand is 6 feet thick at mean lower low water, and becomes thicker towards the backshore.

Rock is exposed about 100 feet offshore, continuing to a steep slope at the base of which is sand. Scattered heads of coral grow along the crest of this slope. Upon the gentler slopes of this rock surface there are large, isolated sand ripples. A strong current sweeps seaward. Hamoa Beach is a popular local surfing beach.

Puu Olai M-6. (Figure 68.) This beach lies immediately south of the cinder cone of Puu Olai near the southwest point of East Maui. Puu Olai Beach is more than 3300 feet in length, extending as a straight beach from lava outcropping at the southeast end to the cliffed deposits of Puu Olai cone. The width of the beach varies by as much as 100 feet from early summer to late winter. The maximum width of more than 200 feet observed during this study was attained during winter, resulting in the formation of four large berms. Large cusps are common at the northwestern end. The predominantly calcareous sand is a poorly sorted mixture of almost all sand sizes with some fine gravel sizes as well.

Dunes covered with kiawe trees form the backshore. Sand thickness at sea level is greater than 15 feet.

Rock predominates offshore except for a large sand pocket roughly paralleling the coastline. Rip currents are generated periodically off the cusp troughs. The steep foreslope is a product of the large waves which frequently strike the beach.

Makena M-6. (Figure 69.) Makena Beach, on the western coast of East Maui, is a slightly arcuate beach about 1000 feet long. Points of lava terminate the beach at either end. During the period of observation the beach gained in width only during the early summer; during the rest of the year its width remained about the same. Onshore, the beach sand is only 3 feet thick, overlying rock. The sand is entirely calcareous, and is well sorted and coarse in grain size. Extensive dunes covered with kiawe trees occupy the backshore.

The offshore area is rocky, with sand overlying the rock in a thin veneer and in scattered sand pockets.

Keawakapu M-6. (Figure 70.) The beach at Keawakapu is midway between Kihei and Puu Olai, along the western coast of East Maui. It is slightly arcuate, over 2000 feet long, with points of lava that outcrop at both ends. During the winter of 1962-1963, Keawakapu Beach was severely eroded by repeated storms from the south, which resulted in considerable property damage to private beach homes located on the low sandy terrace behind the beach. The sand is fine, well sorted, and almost entirely a mixture of calcareous particles.

Thick sand lies off the central portion of the beach. To the south, the bottom is largely lava, and to the north it is a coral reef. During the winter, boulders, cobbles, and pebbles are exposed on the beach.

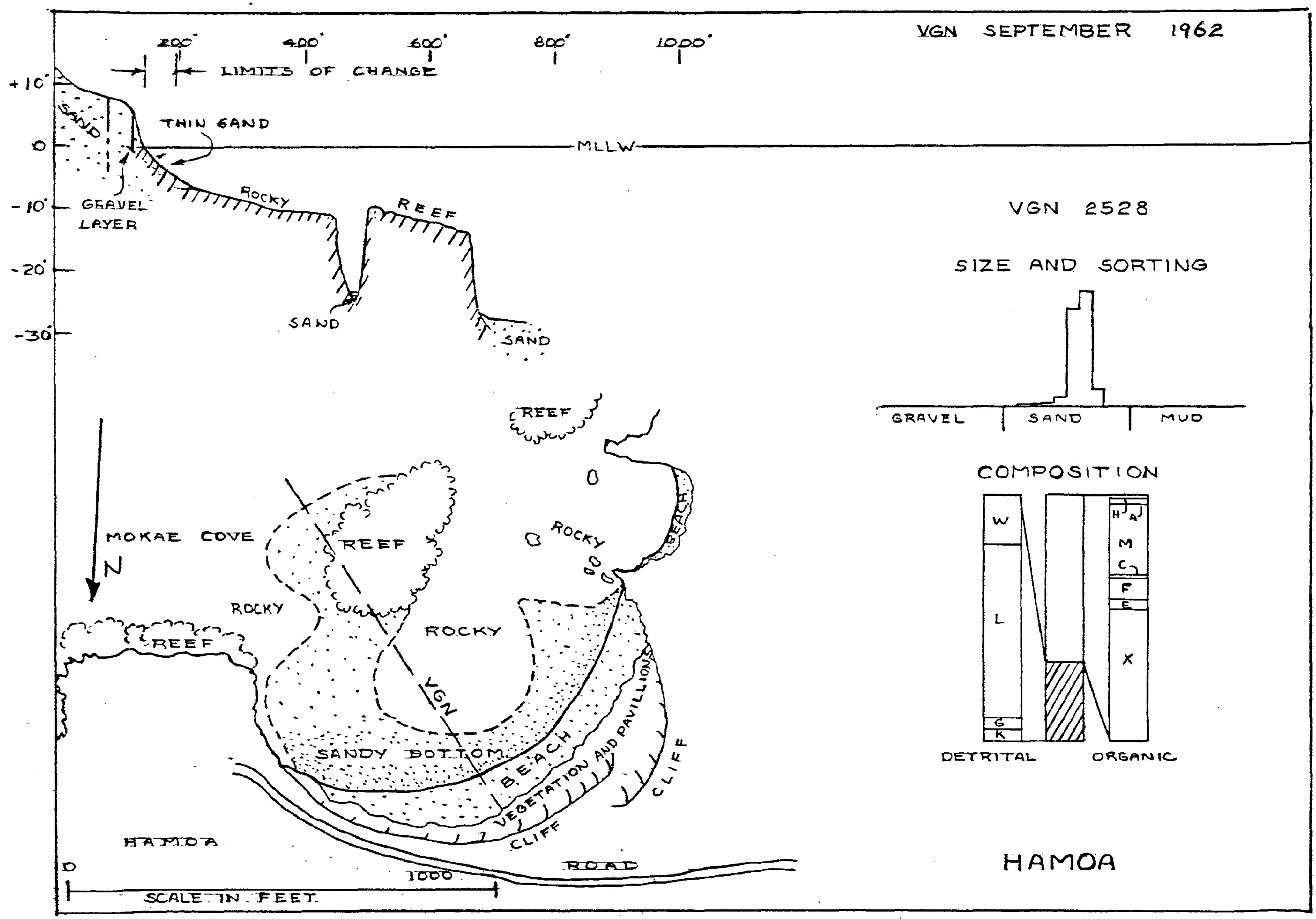

VGN SEPTEMBER 1962
200'
400'
600'
800'
1000'
LIMITS OF CHANGE
+10'
0
-10'
-20'
-30'
SAND
THIN SAND
MLLW
GRAVEL LAYER
ROCKY
REEF
SAND
SAND
VGN 2528
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
K
H
A
M
C
F
E
X
DETRITAL
ORGANIC
HAMOA
N
MOKAE COVE
REEF
ROCKY
REEF
ROCKY
REEF
ROCKY
BEACH
VGN
SANDY BOTTOM
BEACH
VEGETATION AND PAVILLIONS
CLIFF
CLIFF
HAMOA
ROAD
0
1000
SCALE IN FEET

Fig. 67

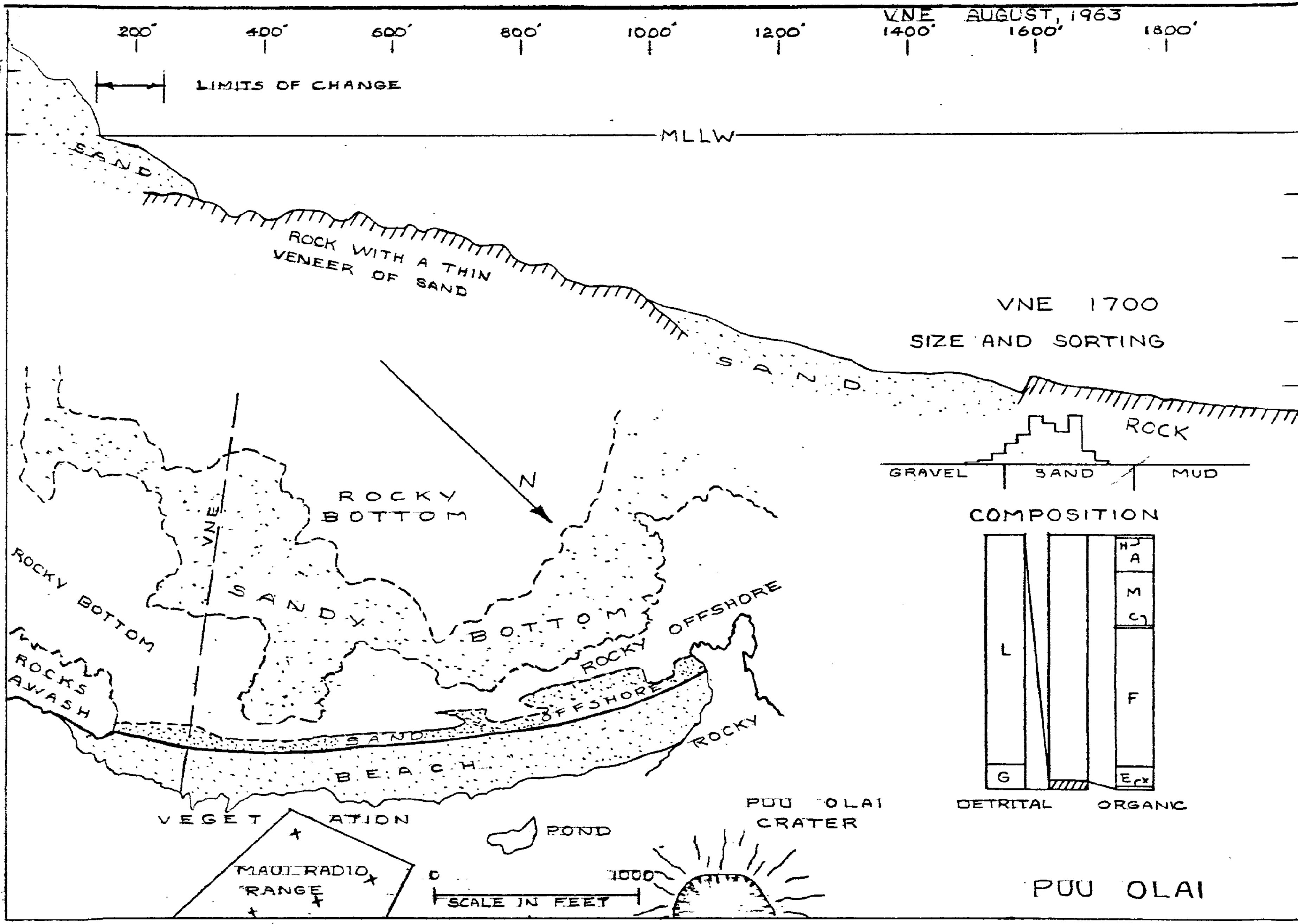

VNE AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10'
0
LIMITS OF CHANGE
MLLW
0
10'
20'
30'
40'
SAND
ROCK WITH A THIN VENEER OF SAND
SAND
VNE 1700
SIZE AND SORTING
ROCK
GRAVEL
SAND
MUD
COMPOSITION
L
G
H
A
M
C
F
E
DETRITAL
ORGANIC
N
ROCKY BOTTOM
VNE
SANDY BOTTOM
ROCKY BOTTOM
ROCKS AWASH
ROCKY OFFSHORE
OFFSHORE
SAND
BEACH
ROCKY
VEGETATION
MAUI RADIO RANGE
POND
PUU OLAI CRATER
0
1000
SCALE IN FEET
PUU OLAI

Fig. 68

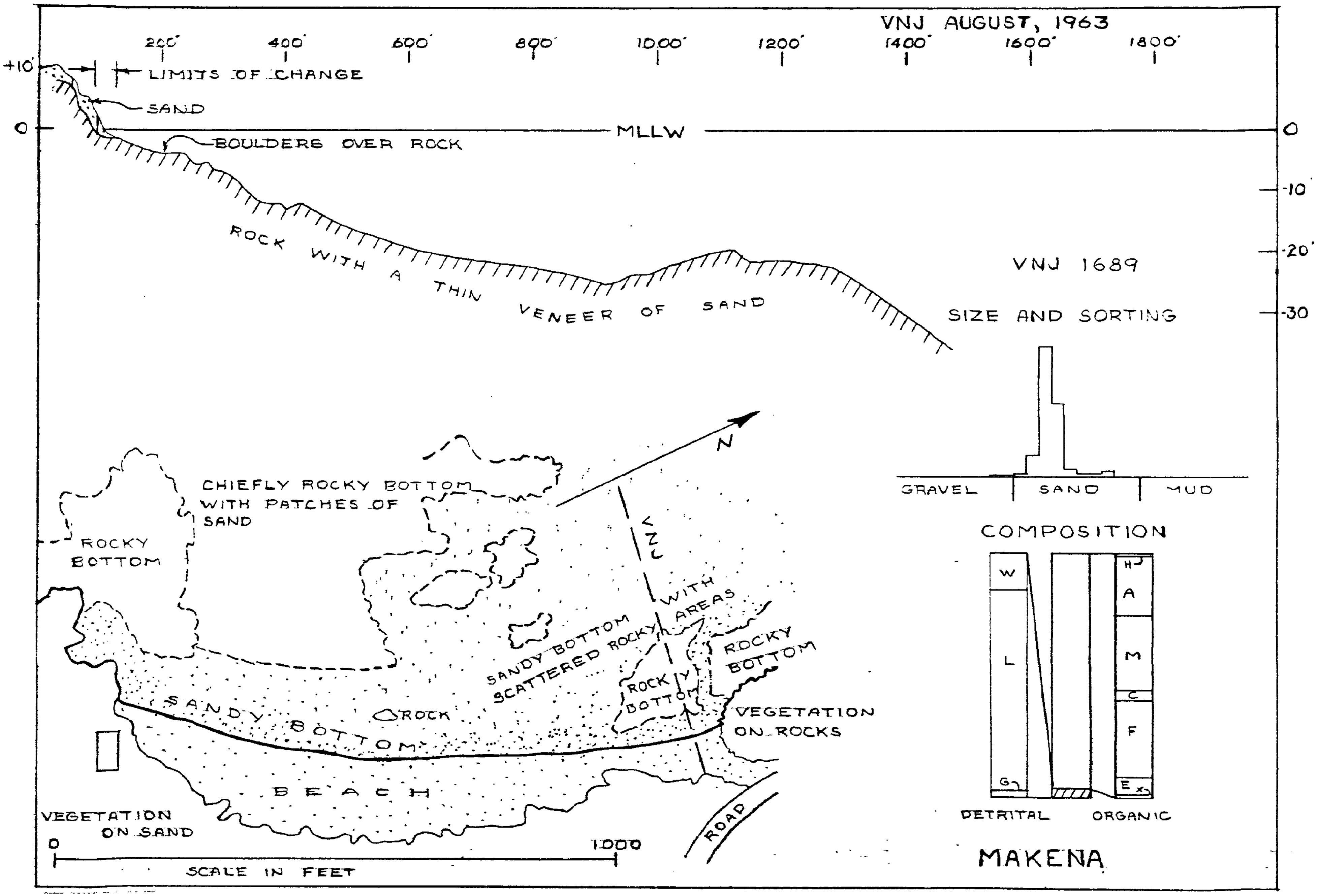

VNJ AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10'
0
-10'
-20'
-30
LIMITS OF CHANGE
SAND
MLLW
BOULDERS OVER ROCK
ROCK WITH A THIN VENEER OF SAND
VNJ 1689
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
H
J
A
M
C
F
E
X
DETRITAL
ORGANIC
MAKENA
N
CHIEFLY ROCKY BOTTOM WITH PATCHES OF SAND
ROCKY BOTTOM
VNJ
WITH AREAS
SANDY BOTTOM SCATTERED ROCKY
ROCKY BOTTOM
ROCKY BOTTOM
VEGETATION ON ROCKS
ROCK
SANDY BOTTOM
BEACH
ROAD
VEGETATION ON SAND
0
1000
SCALE IN FEET

Fig. 69

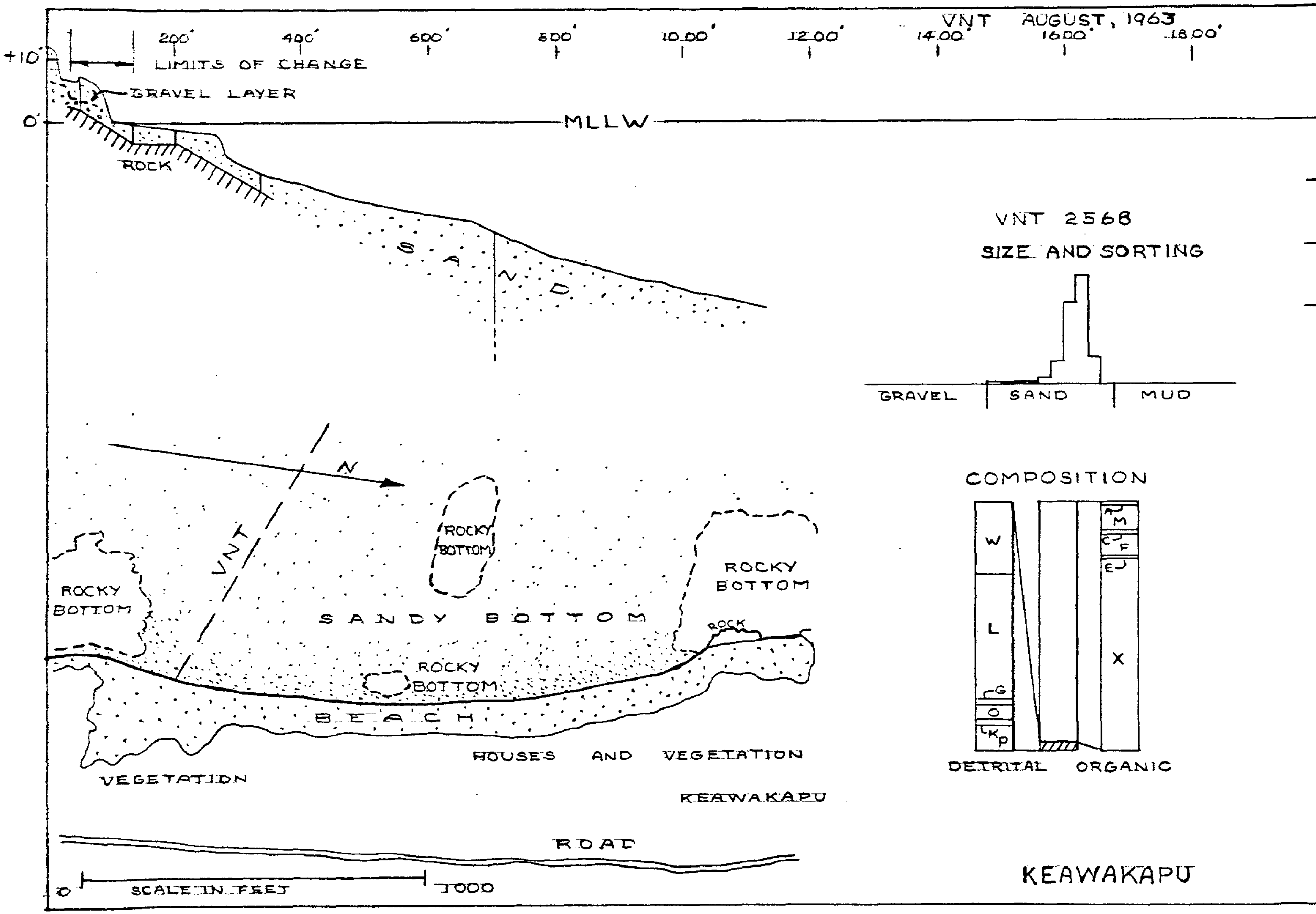

VNT AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
+10'
0'
LIMITS OF CHANGE
GRAVEL LAYER
MLLW
ROCK
SAND
0
-10'
-20'
-30'
VNT 2568
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
O
Kp
A
M
C
F
E
X
DETRITAL
ORGANIC
N
VNT
ROCKY BOTTOM
ROCKY BOTTOM
ROCKY BOTTOM
ROCKY BOTTOM
SANDY BOTTOM
ROCK
BEACH
VEGETATION
HOUSES AND VEGETATION
KEAWAKAPU
ROAD
0
SCALE IN FEET
1000
KEAWAKAPU

Fig. 70

Kalama M-6. (Figure 71.) Kalama Beach Park lies along the west coast of East Maui, 4 miles south of Kihei. Its beach occupies the southern end of a narrow, almost continuous beach which extends northward along this reef-lined coast. At the beach park, the 70-foot-wide beach changes very little during the year. There is only a small percentage of volcanic fragments in the very poorly sorted sand and gravel sediment. Sand is blowing inland from the beach, as can be seen by the buried legs of picnic tables.

A reef about 1200 feet wide extends offshore. Its surface near the shore is mantled by a thin veneer of sand which in some areas becomes large sand pockets. The shallow reef inhibits most swimming activities.

Kihei M-7. (Figure 72.) The beach at Kihei is the eastern end of a 4-mile stretch of continuous beach along the southern coast of the isthmus of Maui. The width at Kihei varies by 60 feet, with a maximum width in summer and a minimum width in late winter. The sand is coarse in grain size, well-sorted, and composed equally of both calcareous and volcanic material. Low dunes, leveled in the construction of beach homes, line the backshore.

Sand lies offshore as a thick covering over rock. An alongshore current to the southeast flows during the late summer, although the old pier modifies its effect greatly near the beach.

Maalaea M-7. (Figure 73.) This beach is located at the western end of Maalaea Bay, along the southern coast of the isthmus of Maui and near the village of Maalaea. During the period of study, maximum accretion occurred during late winter when the beach became nearly 110 feet wide. Minimum width occurred during early fall. The sand is moderately well-sorted with only a slight admixture of volcanic constituents. Sediment-filled salt ponds form the backshore.

Rock lies offshore and is covered with numerous sand pockets. Near the shore a continuous band of sand parallels the beach.

<u>Olowalu</u> M-7. (Figure 74.) This beach lies east of Olowalu at Mopua on the southwest coast of West Maui, and is only a segment of the narrow beach which rims this coastline. There is little change to the beach during the year. Maximum width of about 40 feet is reached during the winter. The sand is well-sorted, and is composed largely of volcanic grains. Vines cover the sandy backshore to the highway.

A coral reef lying offshore is cut by small channels and pockets of sand. A moderately strong alongshore current moving to the south was noticed during late summer.

<u>Makila</u> M-8. (Figure 75.) Makila Beach lies south of both Lahaina and Makila along the southwest coast of West Maui, and is typical of the numerous small gravel beaches common to this coastal area. During the year, the 35-foot-wide beach changes very little. The ratio of sand to gravel and boulders changes markedly, however. The sediment is an extremely poorly sorted mixture of both volcanic and calcareous grains of all sizes coarser than mud. A beach park occupies the backshore.

The reef flat of the coral reef offshore is paved with gravel and boulders, with only a few scattered patches of sand.

<u>Hanakoo Point</u> M-8. (Figure 76.) This beach, along the westernmost point of Maui south of Kaanapali, is a 2-1/4-mile-long cuspate foreland beach. Immediately north of Hanakoo Point the beach reaches a maximum width of 80 feet during late winter and early spring. However during

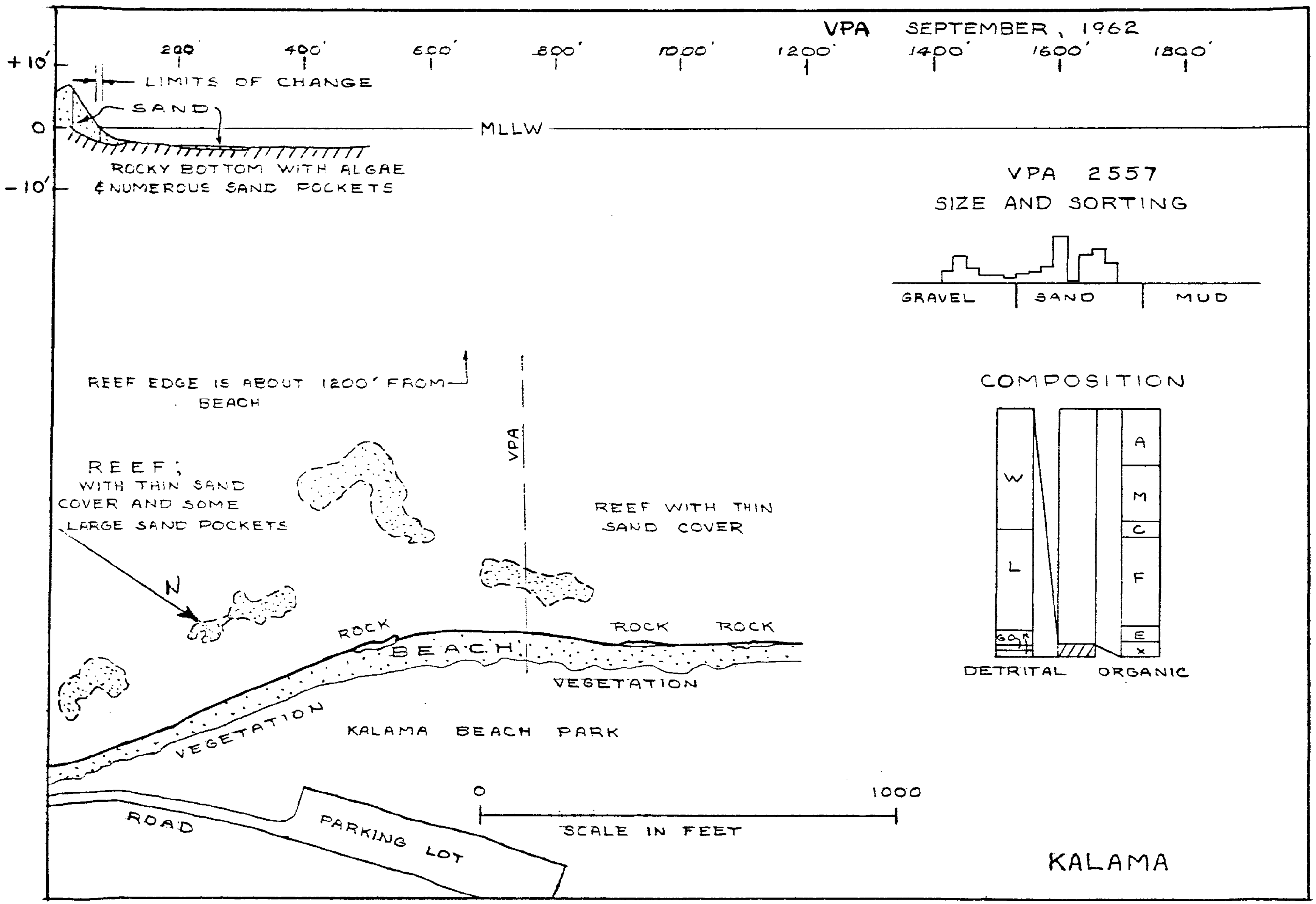

VPA SEPTEMBER, 1962
+10'
0
-10'
200
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
SAND
MLLW
ROCKY BOTTOM WITH ALGAE
& NUMEROUS SAND POCKETS
VPA 2557
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
A
M
C
F
E
X
DETRITAL
ORGANIC
REEF EDGE IS ABOUT 1200' FROM BEACH
VPA
REEF;
WITH THIN SAND
COVER AND SOME
LARGE SAND POCKETS
N
REEF WITH THIN
SAND COVER
ROCK
ROCK
ROCK
BEACH
VEGETATION
VEGETATION
KALAMA BEACH PARK
ROAD
PARKING LOT
0
1000
SCALE IN FEET
KALAMA

Fig. 71

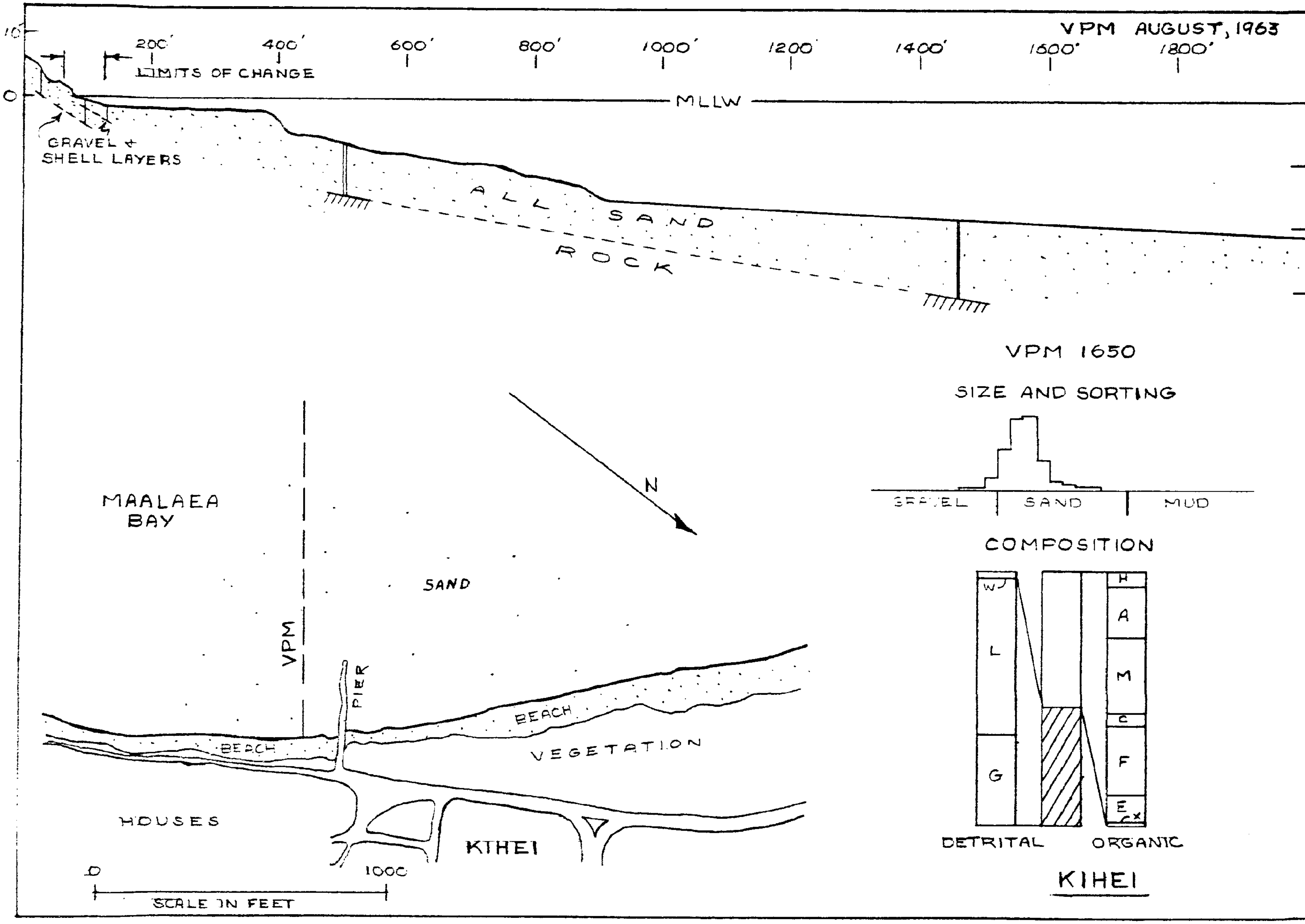

VPM AUGUST, 1963
LIMITS OF CHANGE
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
0
-10'
-20'
-30'
10'
GRAVEL + SHELL LAYERS
ALL SAND
ROCK
VPM 1650
SIZE AND SORTING
SAND
MUD
COMPOSITION
WJ
L
G
H
A
M
C
F
E
CX
DETRITAL
ORGANIC
KIHEI
MAALAEA BAY
SAND
N
VPM
PIER
BEACH
VEGETATION
HOUSES
KIHEI
0
1000
SCALE IN FEET

Fig. 72

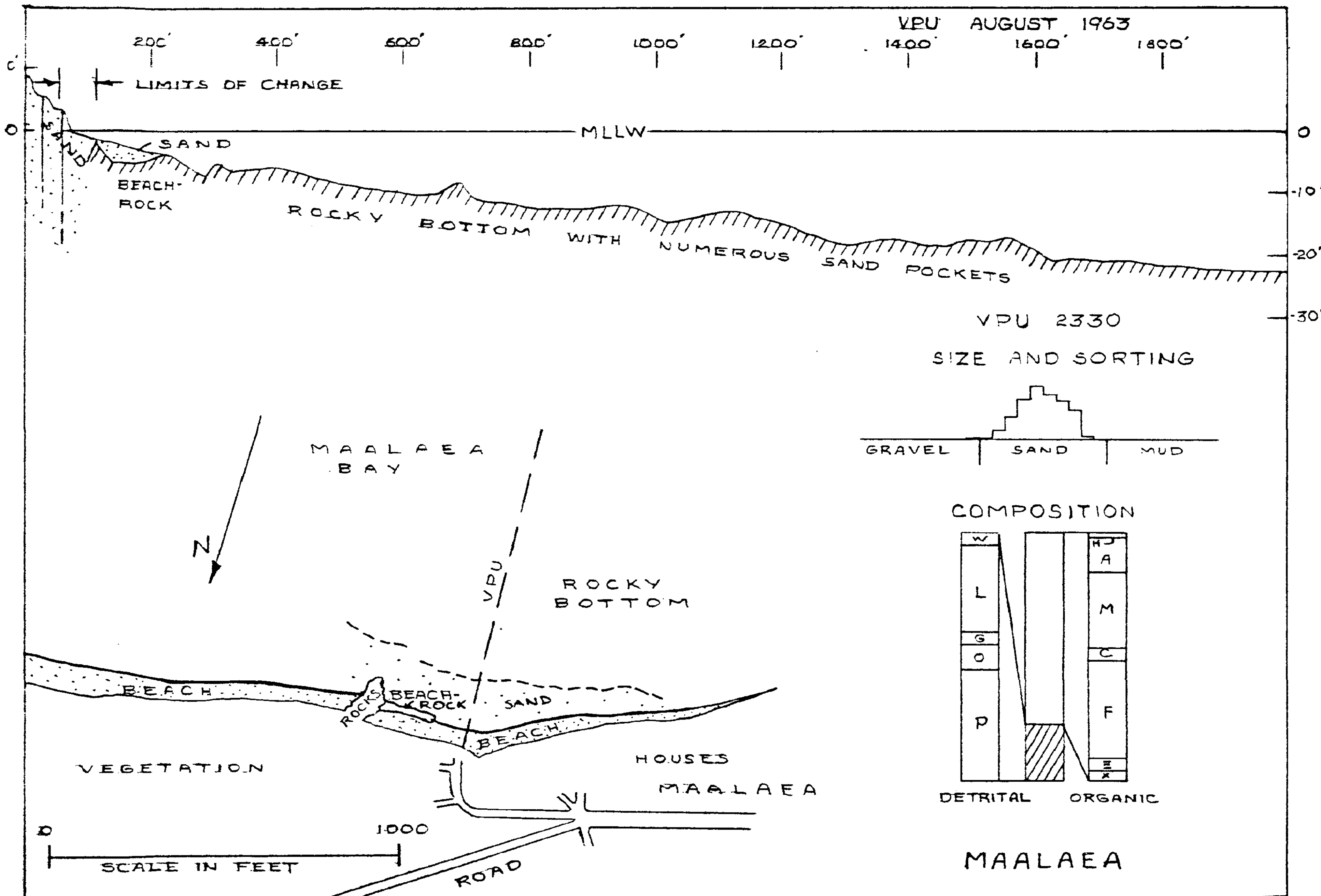

VPU AUGUST 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
MLLW
0
-10'
-20'
-30'
SAND
BEACH-ROCK
ROCKY BOTTOM WITH NUMEROUS SAND POCKETS
VPU 2330
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
O
P
A
M
C
F
DETRITAL
ORGANIC
MAALAEA
MAALAEA BAY
N
VPU
ROCKY BOTTOM
BEACH
ROCKS
BEACH-ROCK
SAND
BEACH
HOUSES
MAALAEA
VEGETATION
0
1000
SCALE IN FEET
ROAD

Fig. 73

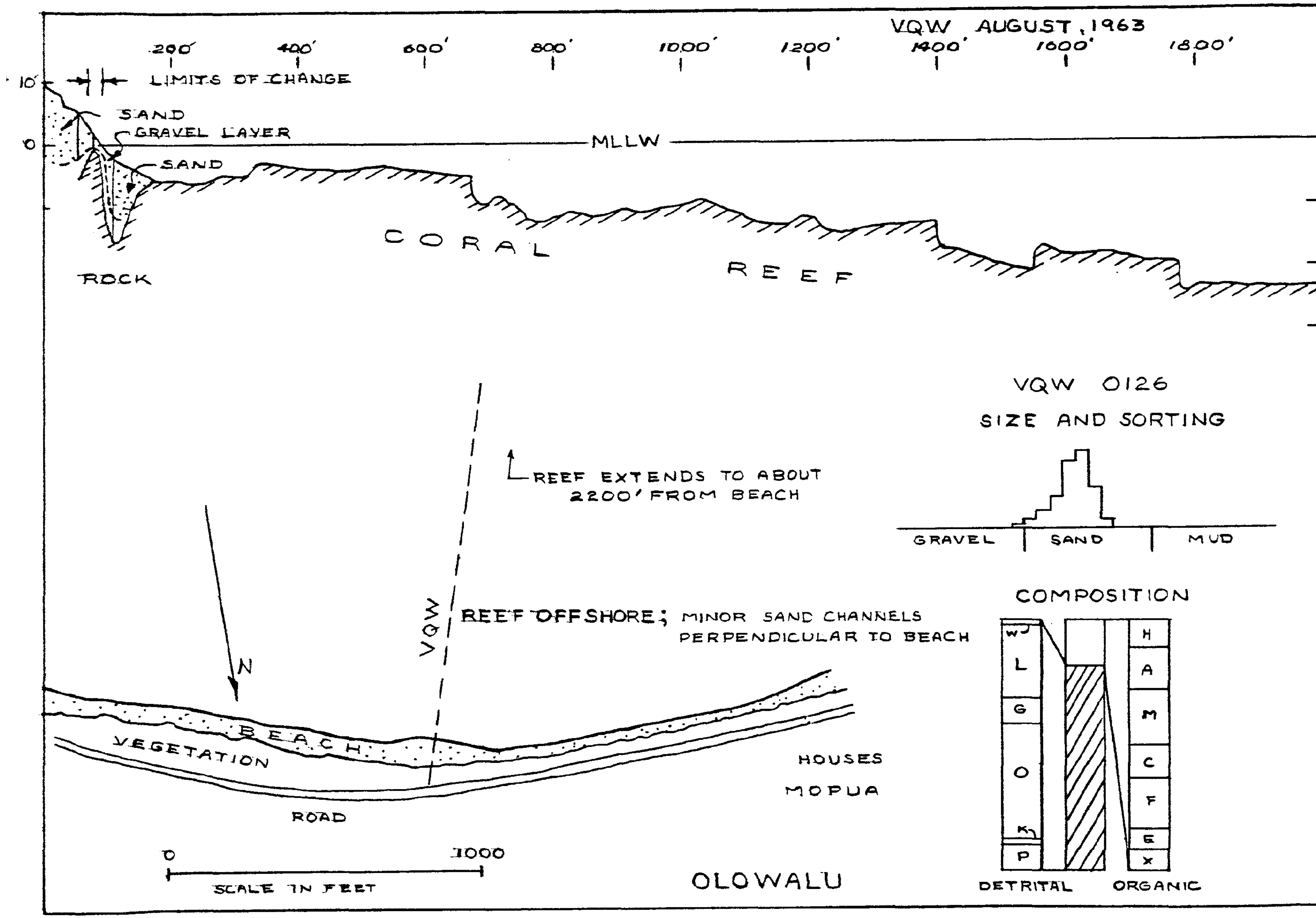
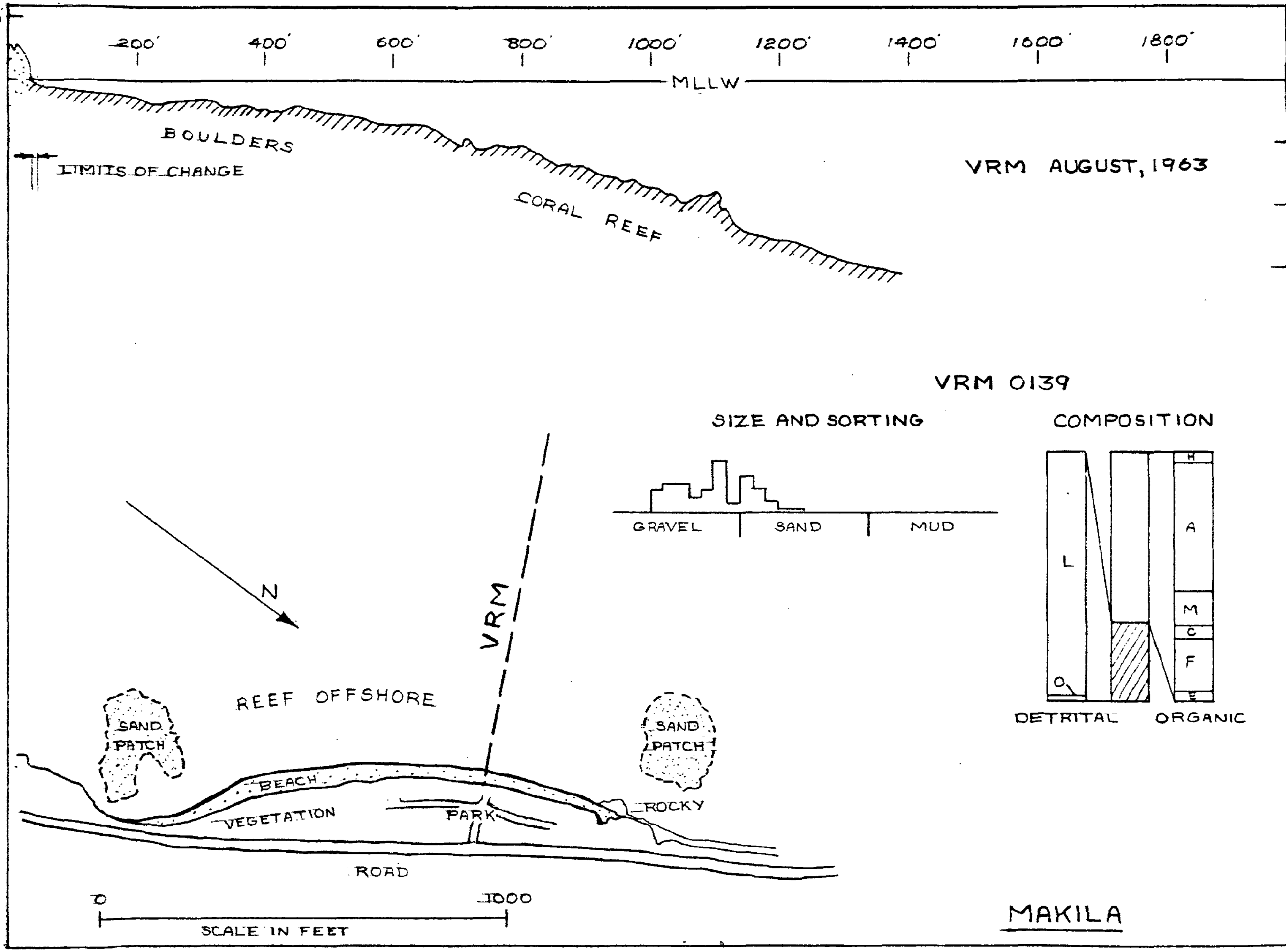

VQW AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
10'
0
-10'
-20'
-30'
LIMITS OF CHANGE
SAND
GRAVEL LAYER
SAND
MLLW
ROCK
CORAL
REEF
VQW 0126
SIZE AND SORTING
GRAVEL
SAND
MUD
REEF EXTENDS TO ABOUT
2200' FROM BEACH
N
VQW
REEF OFFSHORE; MINOR SAND CHANNELS
PERPENDICULAR TO BEACH
COMPOSITION
W
L
G
O
K
P
H
A
M
C
F
E
X
DETRITAL
ORGANIC
BEACH
VEGETATION
ROAD
HOUSES
MOPUA
0
1000
SCALE IN FEET
OLOWALU

Fig. 74



10
0
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
MLLW
-10'
-20'
-30'
BOULDERS
LIMITS OF CHANGE
CORAL REEF
VRM AUGUST, 1963
VRM 0139
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
L
O
H
A
M
C
F
E
DETRITAL
ORGANIC
N
VRM
REEF OFFSHORE
SAND PATCH
SAND PATCH
BEACH
VEGETATION
PARK
ROCKY
ROAD
0
1000
SCALE IN FEET
MAKILA

Fig. 75

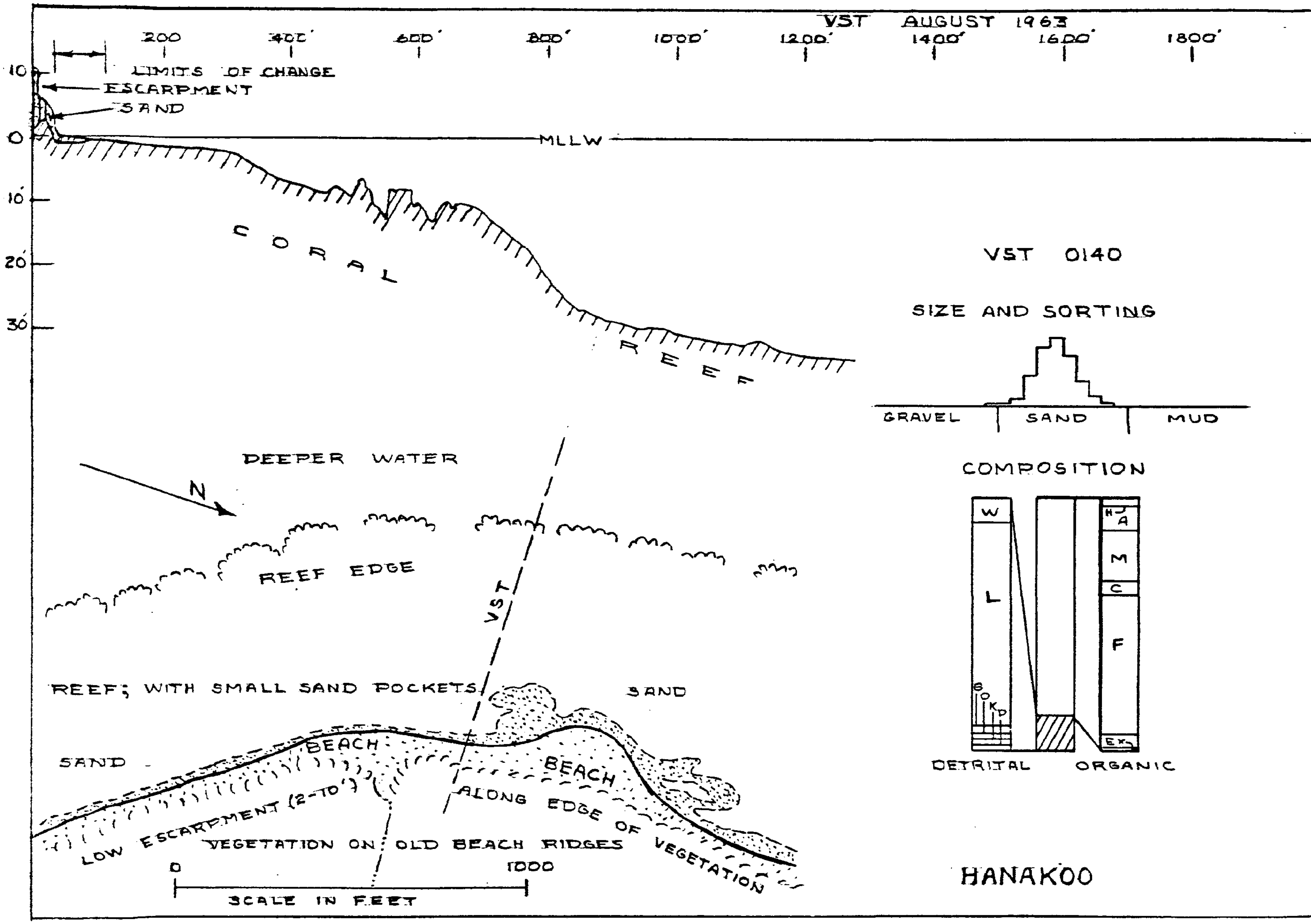

VST AUGUST 1963
200
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
10
0
10'
20'
30'
LIMITS OF CHANGE
ESCARPMENT
SAND
MLLW
CORAL
REEF
VST 0140
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
O
K
D
H
A
M
C
F
EX
DETRITAL
ORGANIC
DEEPER WATER
N
REEF EDGE
VST
REEF; WITH SMALL SAND POCKETS
SAND
SAND
BEACH
BEACH
ALONG EDGE OF VEGETATION
LOW ESCARPMENT (2-10')
VEGETATION ON OLD BEACH RIDGES
0
1000
SCALE IN FEET
HANAKOO

Fig. 76

the summer, sand apparently drifts to the north, leaving the beach at Hanakoo Point only 30 feet wide. Then, immediately north of the broad point, serious erosion occurs to the backshore. This resulted in a 15-foot-high escarpment during the summer of 1963. In the past year or two erosion has exceeded deposition, as shown by the complete undermining of the wooden triangulation tower at the point. However, numerous beach ridges, all paralleling the present coastline, form the backshore area, and indicate a long-term history of accretion.

A prolific coral reef lies off the point; its backreef dotted by numerous small pockets of sand. Extreme wave convergences mark this area.

Kaanapali M-8. (Figure 77.) Kaanapali Beach is north of Lahaina, along the western coast of West Maui. The beach is slightly arcuate in plan view and is about 4000 feet long. Kehaa Point, a littoral cinder cone now covered with resort buildings, lies to the north, whereas to the south the beach is continuous with the beach described at Hanakoo Point. During summer the sand apparently is moved to the northern end of the beach creating a beach more than 200 feet wide, but in winter the sand is shifted to the south, producing a broad bulge north of Hanakoo Point. The sand is a well sorted, medium-sized mixture of predominantly calcareous fragments. Numerous beach ridges parallel the shoreline along the backshore, and these ridges are mantled by wind-blown sand.

Rock ridges and sand pockets alternate offshore. A well-developed berm and a moderately steep foreslope usually characterize the beach profile. These features reflect the large swell which seasonally arrives here.

Napili M-9. (Figure 78.) Napili Beach lies at the head of Napili Bay at the northwest tip of West Maui. Bound at both ends by low rocky cliffs, the beach is a large arcuate pocket beach more than 1000 feet long. Moderate erosion of the beach occurs only in the late winter, whereas the width remains essentially constant during the rest of the year. The sand is a well sorted, predominantly calcareous mixture of medium grain size. Houses and new hotels line the backshore.

The offshore area is predominantly reef with large pockets of sand.

Fleming's Beach M-9. (Figure 79.) Fleming's Beach is a small pocket beach at the northwestern tip of West Maui. It is about 600 feet in length with an almost constant width of about 85 feet. Both ends of the beach terminate against rocky points of lava. The sand is a well-sorted, coarse, and predominantly calcareous sediment. The backshore area is divided into three areas. The southernmost park is open to the public, the central area is a local pineapple company's beach park, and there is a private park to the north. Access to all three is excellent, and swimming conditions are good.

Rock that lies offshore is partly covered by a veneer of sand 2-1/2 feet or less in thickness. Rocks are awash off the southern point.

Honokahua M-9. (Figure 80.) Honokahua Beach lies at the northwest tip of West Maui near the end of the present paved highway. It is a 1500-foot-long, straight beach between points of lava. During late summer the beach is about 165 feet at its maximum width. Throughout the rest of the year this varies by only 20 feet with the minimum occurring during late winter. A well-sorted, medium-grain-size sand, largely of calcareous debris, forms the beach sediment. Ironwood trees

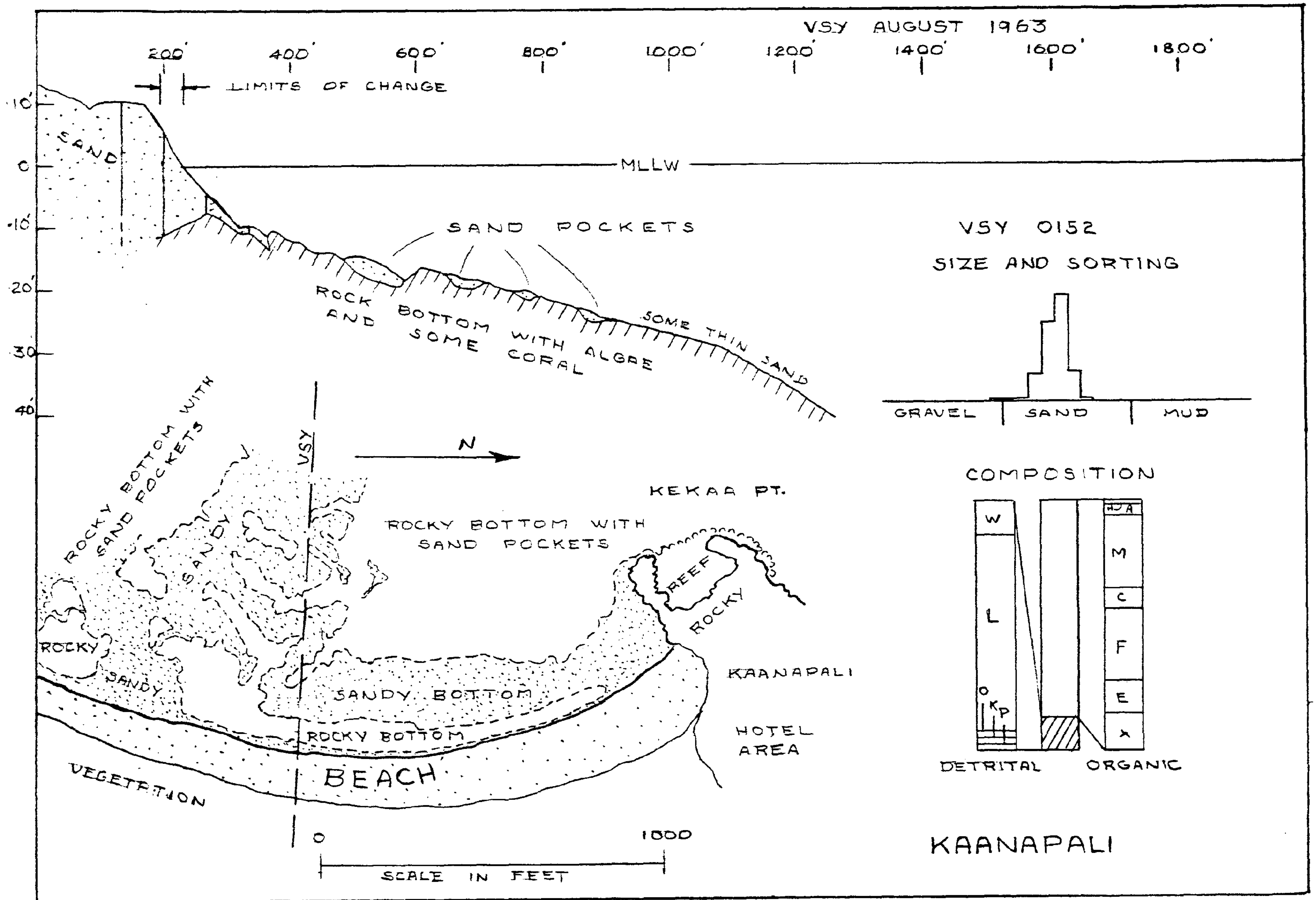

VSY AUGUST 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
10'
0
10'
20'
30'
40'
SAND
MLLW
SAND POCKETS
ROCK BOTTOM WITH ALGAE AND SOME CORAL
SOME THIN SAND
VSY 0152
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
K
P
M
C
F
E
X
A
DETRITAL
ORGANIC
N
VSY
KEKAA PT.
ROCKY BOTTOM WITH SAND POCKETS
ROCKY BOTTOM WITH SAND POCKETS
SANDY
REEF
ROCKY
KAANAPALI
HOTEL AREA
ROCKY
SANDY
SANDY BOTTOM
ROCKY BOTTOM
BEACH
VEGETATION
0
1000
SCALE IN FEET
KAANAPALI

Fig. 77

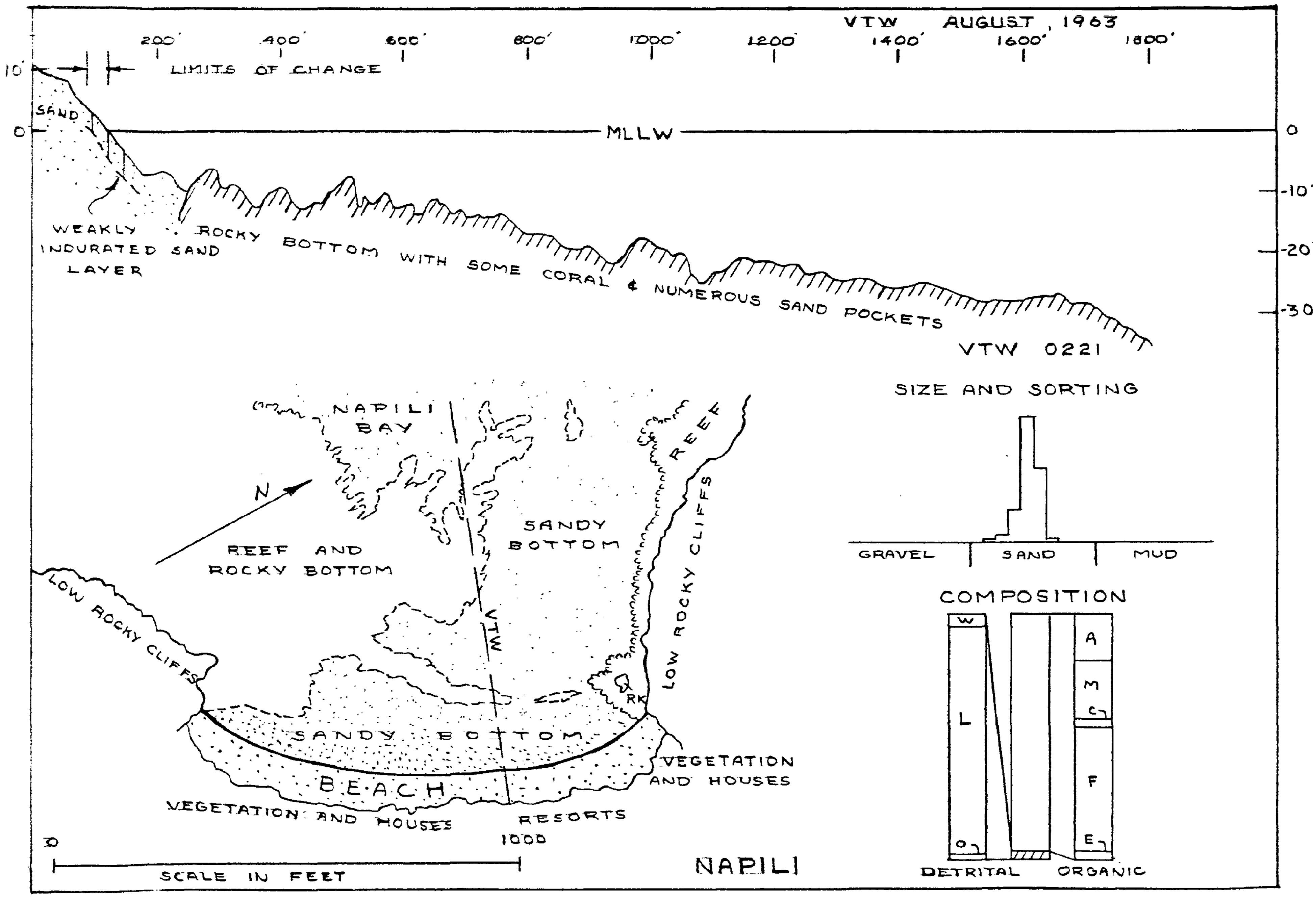

VTW AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
10'
0
-10'
-20'
-30
LIMITS OF CHANGE
SAND
MLLW
WEAKLY INDURATED SAND LAYER
ROCKY BOTTOM WITH SOME CORAL & NUMEROUS SAND POCKETS
VTW 0221
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
A
M
C
F
E
DETRITAL
ORGANIC
NAPILI BAY
N
REEF AND ROCKY BOTTOM
SANDY BOTTOM
REEF
VTW
LOW ROCKY CLIFFS
LOW ROCKY CLIFFS
RK
SANDY BOTTOM
BEACH
VEGETATION AND HOUSES
VEGETATION AND HOUSES
RESORTS
0
1000
SCALE IN FEET
NAPILI

Fig. 78

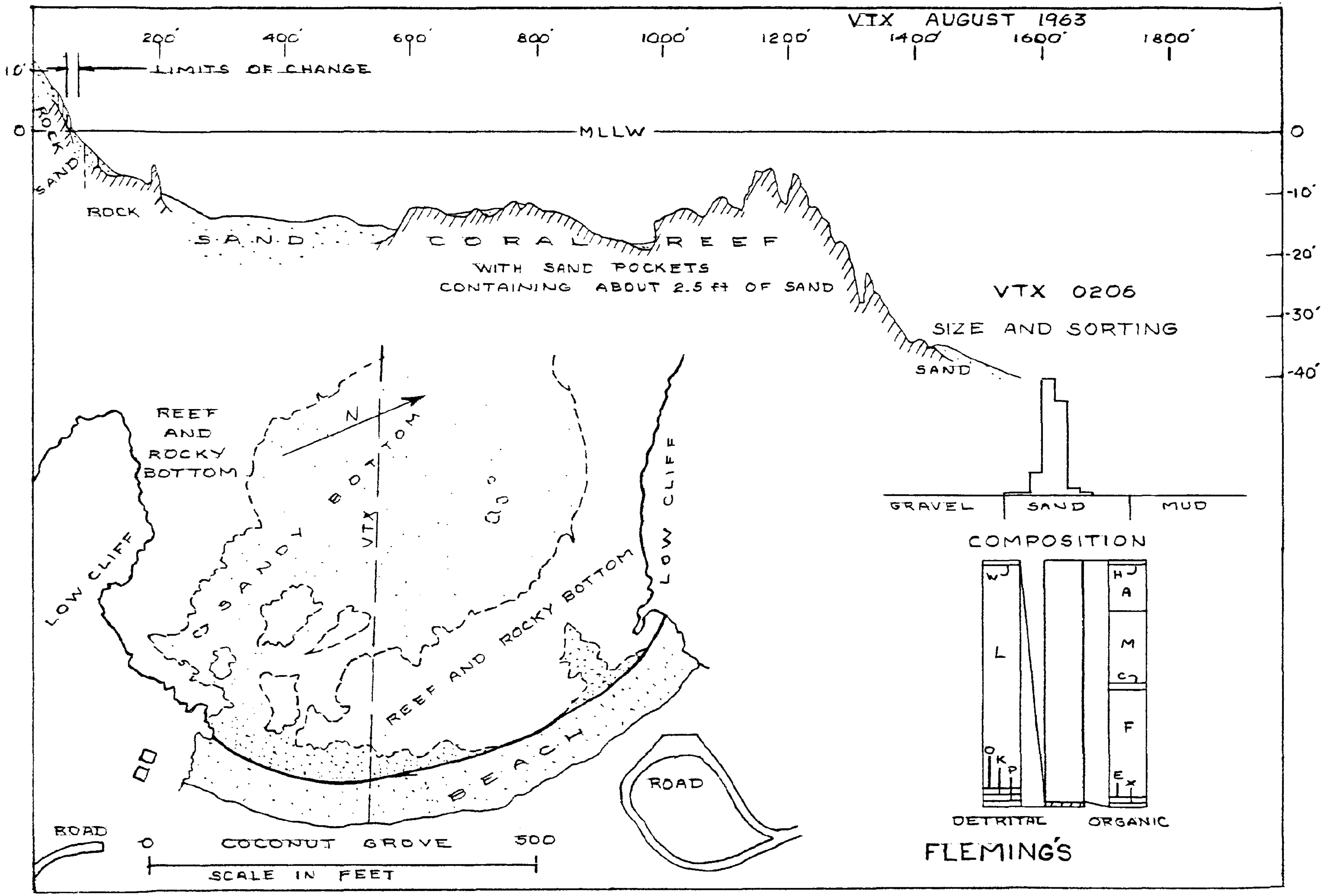

VTX AUGUST 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
10'
0
-10'
-20'
-30'
-40'
LIMITS OF CHANGE
MLLW
ROCK
SAND
ROCK
SAND
CORAL REEF
WITH SAND POCKETS
CONTAINING ABOUT 2.5 ft OF SAND
SAND
VTX 0206
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
DETRITAL
ORGANIC
FLEMING'S
REEF AND ROCKY BOTTOM
N
SAND BOTTOM
VTX
LOW CLIFF
LOW CLIFF
REEF AND ROCKY BOTTOM
BEACH
ROAD
ROAD
0
500
COCONUT GROVE
SCALE IN FEET

Fig. 79

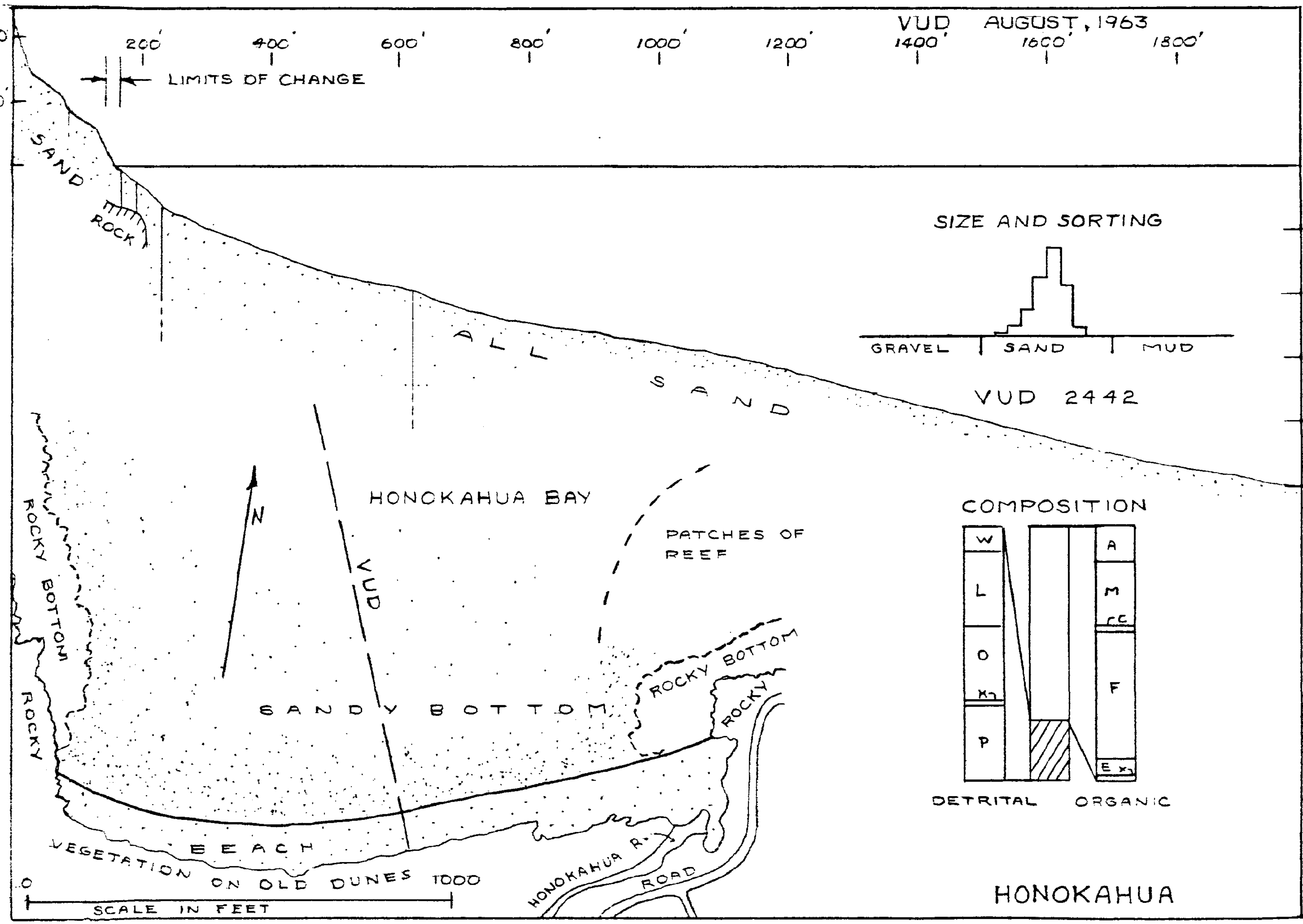

VUD AUGUST, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
LIMITS OF CHANGE
20'
10'
0
0
-10'
-20'
-30'
-40'
-50'
SAND
ROCK
ALL SAND
SIZE AND SORTING
GRAVEL
SAND
MUD
VUD 2442
HONOKAHUA BAY
N
VUD
PATCHES OF REEF
COMPOSITION
W
L
O
P
A
M
F
DETRITAL
ORGANIC
ROCKY BOTTOM
ROCKY
SANDY BOTTOM
ROCKY BOTTOM
ROCKY
BEACH
VEGETATION ON OLD DUNES
HONOKAHUA R.
HONOKAHUA ROAD
0
1000
SCALE IN FEET
HONOKAHUA

Fig. 80

grow on large dunes along the backshore.

Deep sand lies offshore and rock appears only adjacent to the rocky promontories. Circulation within the bay apparently is from a shoreward current that enters at the east and returns seaward along the western point.

Hawaii: by F. W. McCoy, Jr.

Hilo H-1. (Figure 81.) Within Hilo Bay on the island of Hawaii there is a small beach, averaging only 35 feet wide and 400 feet long. It is retained by highway fill at its eastern and western ends. The sand thickness is, at the maximum, 6 feet. It is composed almost entirely of volcanic rock fragments of sand size, with very few calcareous constituents. The sand exhibits moderately good sorting at about a medium-grain size. Because of protection within the harbor, the beach undergoes only slight changes throughout the year.

A highway fill occupies the backshore. The present beach represents only a small portion of what was, in the last century, a much wider beach. A railroad embankment constructed about 1901 covered most of the beach. After the 1946 tsunami, wider highway fill along the railroad right-of-way further decreased the width of the beach.

The offshore area is lava rock with a thin veneer of mud and silt. Large blocks of concrete rubble lie offshore, products of the 1960 tsunami.

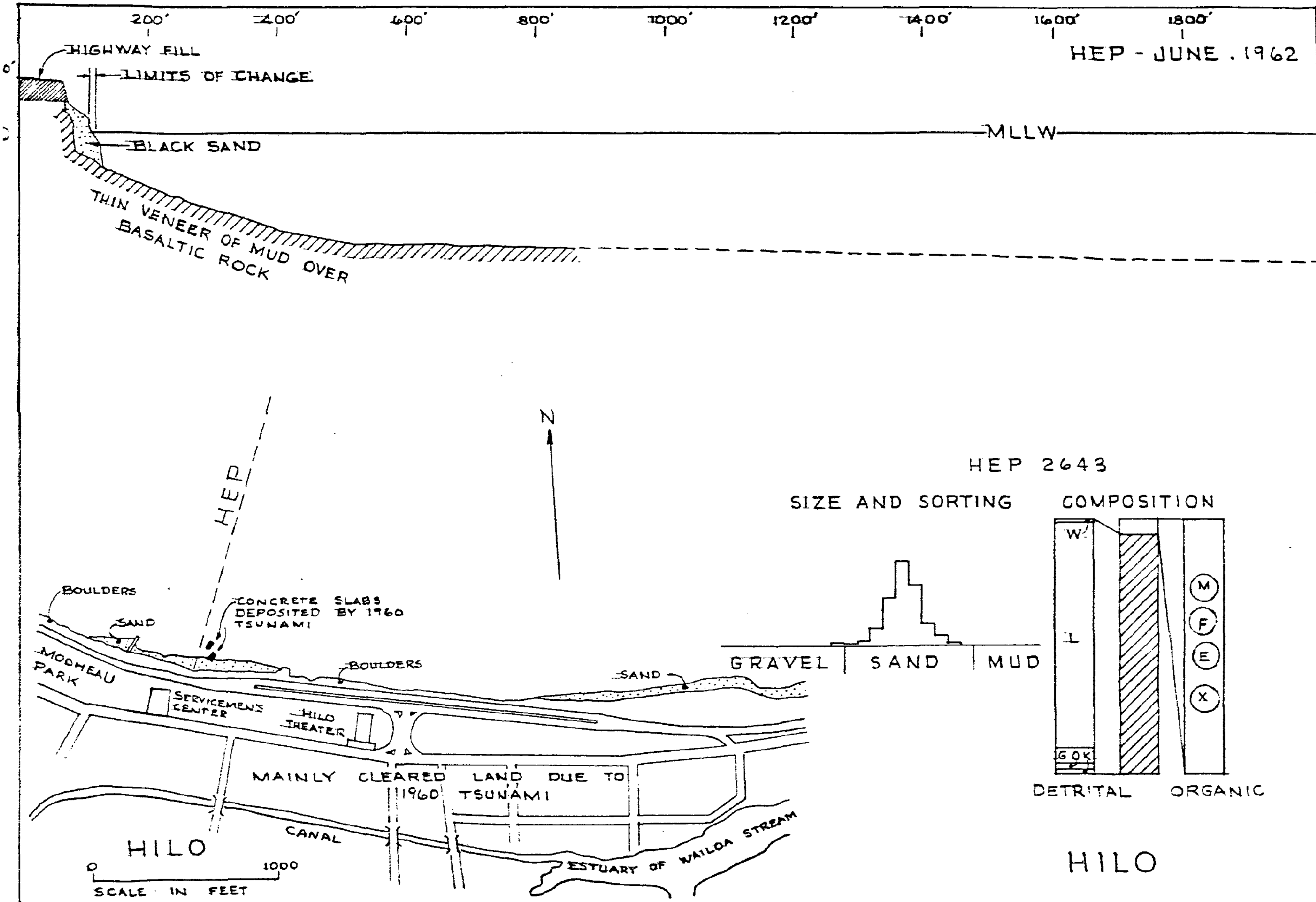
Kaimu H-2. (Figure 82.) This beach lies along the southeast coast of the island of Hawaii, just northeast of the village of Kalapana and is popularly known as Kalapana Beach. In plan view, the black sand beach at Kaimu is slightly arcuate, about 1000 feet long, and varies in width from 70 feet, during late winter, to 118 feet during early fall. The sand is composed almost entirely of volcanic glass and lava fragments (glass predominating) which give the sand its famed black color. The sand is only moderately well sorted and is very coarse in size, with some gravel-size components. Erosion during winter exposes an underlying boulder layer at the northeast end of the beach. The backshore is black sand within a coconut grove which, farther inland, terminates against basaltic rock. This lava also forms projecting points at either end of the beach.

Offshore, the bottom is predominantly rock. Waves are generally rather large, as can be seen by the steep foreslope, and a strong rip current periodically flows off the southwest end of the beach.

Kaimu is the most publicized, and has the easiest access from Hilo, of all of the small, black sand beaches that have been caused by the explosion and chilling of lava flows entering the ocean.

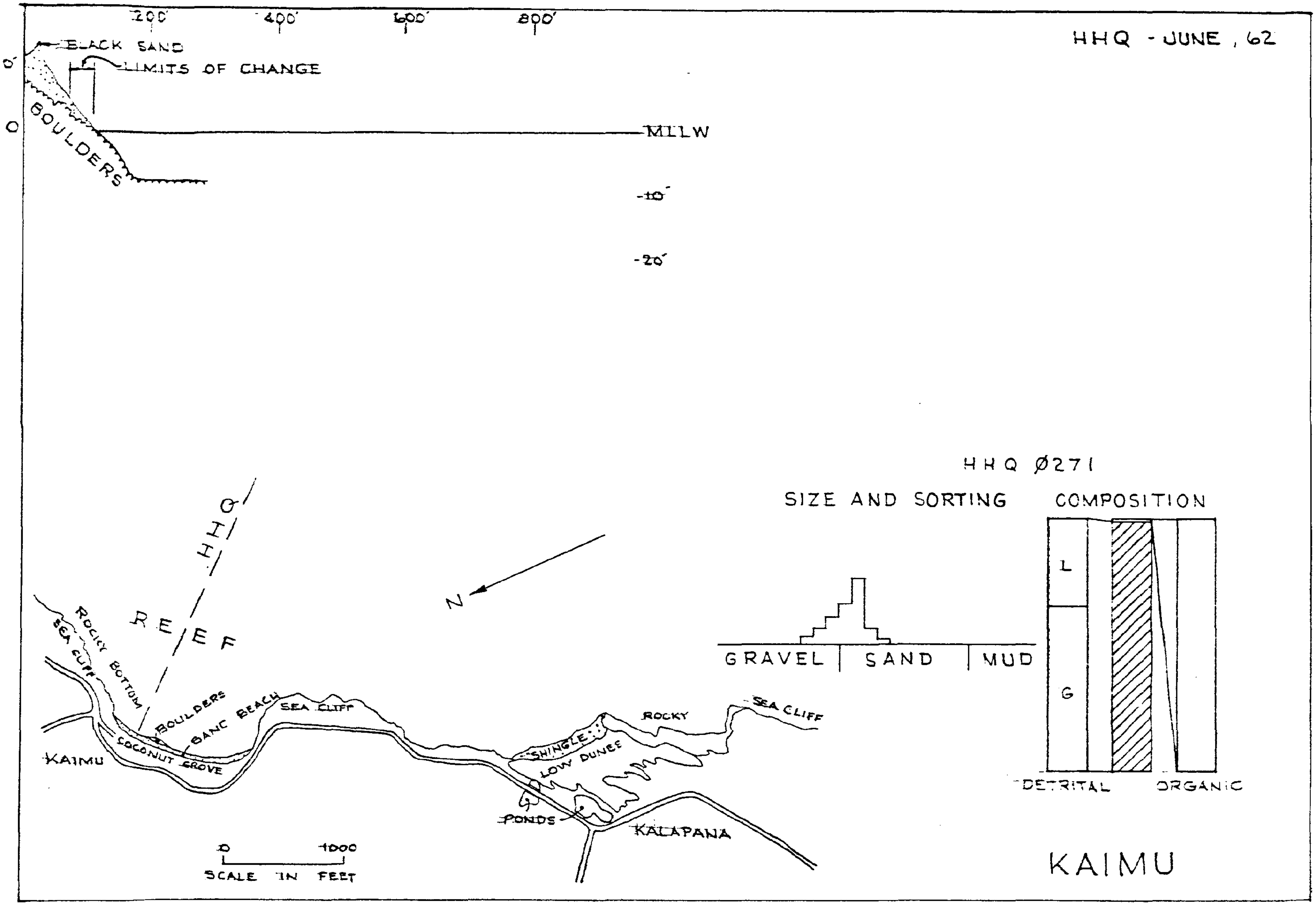
Punaluu H-2. (Figure 83.) Punaluu Beach is a small, arcuate pocket beach of black sand along the southeast coast of the island of Hawaii. It is 800 feet long and 70 feet wide and lies between recent lava flows. There is little change to the beach during the year. The sand is composed almost entirely of volcanic glass, and the sorting is bimodal with modes of very coarse size and medium-size grains. The village of Punaluu occupies the backshore area of wind-blown sand on lava.

Numerous exposures of lava bedrock and lava boulders occur along sea level as well as offshore where they form an irregular natural breakwater.



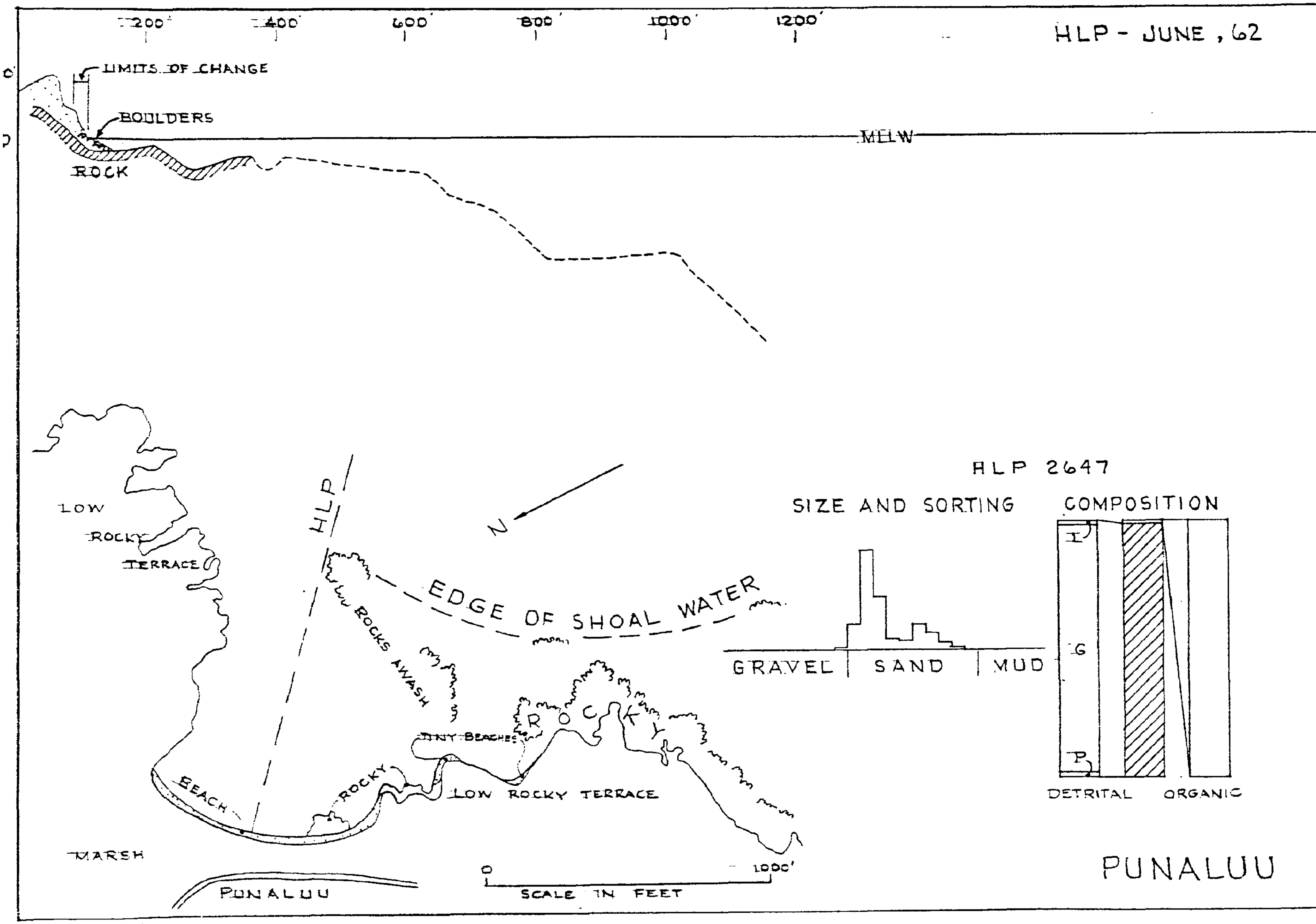
HEP - JUNE . 1962
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
0'
HIGHWAY FILL
LIMITS OF CHANGE
MLLW
0
10'
20'
30'
BLACK SAND
THIN VENEER OF MUD OVER BASALTIC ROCK
N
HEP
HEP 2643
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G O K
DETRITAL
ORGANIC
M
F
E
X
BOULDERS
SAND
CONCRETE SLABS DEPOSITED BY 1960 TSUNAMI
BOULDERS
SAND
MOOHEAU PARK
SERVICEMEN'S CENTER
HILO THEATER
MAINLY CLEARED LAND DUE TO 1960 TSUNAMI
CANAL
ESTUARY OF WAILOA STREAM
HILO
0
1000
SCALE IN FEET
HILO

Fig. 81



HHQ - JUNE, 62
200'
400'
600'
800'
0'
0
BLACK SAND
LIMITS OF CHANGE
BOULDERS
MLLW
-10'
-20'
HHQ Ø271
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
L
G
DETRITAL
ORGANIC
HHQ
REEF
N
ROCKY BOTTOM
SEA CLIFF
BOULDERS
BANC
BEACH
SEA CLIFF
COCONUT GROVE
KAIMU
SHINGLE
LOW DUNES
ROCKY
SEA CLIFF
PONDS
KALAPANA
0
1000
SCALE IN FEET
KAIMU

Fig. 82



HLP - JUNE, 62
200'
400'
600'
800'
1000'
1200'
LIMITS OF CHANGE
BOULDERS
ROCK
MLLW
0
10'
20'
30'
HLP 2647
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
I
G
P
DETRITAL
ORGANIC
LOW
ROCKY
TERRACE
HLP
N
EDGE OF SHOAL WATER
ROCKS AWASH
TINY BEACHES
ROCKY
LOW ROCKY TERRACE
BEACH
MARSH
PUNALUU
0
1000'
SCALE IN FEET
PUNALUU

Fig. 83

Hookena H-3. (Figure 84.) Hookena Beach is an arcuate pocket beach, 600 feet long, in the South Kona district of the west coast of the island of Hawaii. At either end, it is bounded by basaltic rock. To the south and along the backshore this lava bedrock is exposed as a 100-foot-high fault escarpment. Sand extends inland beneath a coconut grove to the talus at the base of the scarp in the backshore area. Nearly equal proportions of volcanic and calcareous grains form the medium-sized, moderately sorted sand. During the 1-year period of measurements, the beach was eroded a maximum of 25 feet during the winter.

A rock reef lies offshore and underlies the beach 3 feet below mean lower low water. Sand extends out about 100 feet from shore, where it then forms only a thin covering over the rock. Some boulders and sparse coral heads lie on this rock surface.

Kealakekua H-3. (Figure 85.) Kealakekua Beach lies along the west coast of the island of Hawaii, immediately northeast of Palemano Point, the southern point of Kealakekua Bay. It is 600 feet long, with a width of about 70 feet during the summer and 50 feet during the winter. The sand is poorly sorted and coarse in size with an auxiliary gravel mode, and is a mixture of grains which is slightly more calcareous than volcanic.

Thick vegetation mantles the backshore. At sea level, patches of sand alternate with lava and with boulders and cobbles of lava and coral. Similar rocks lie awash as much as 300 feet offshore, whereupon the bottom assumes a gentle gradient to a depth of 10 feet at 800 feet from the beach. Beyond this depth the bottom drops off quite rapidly.

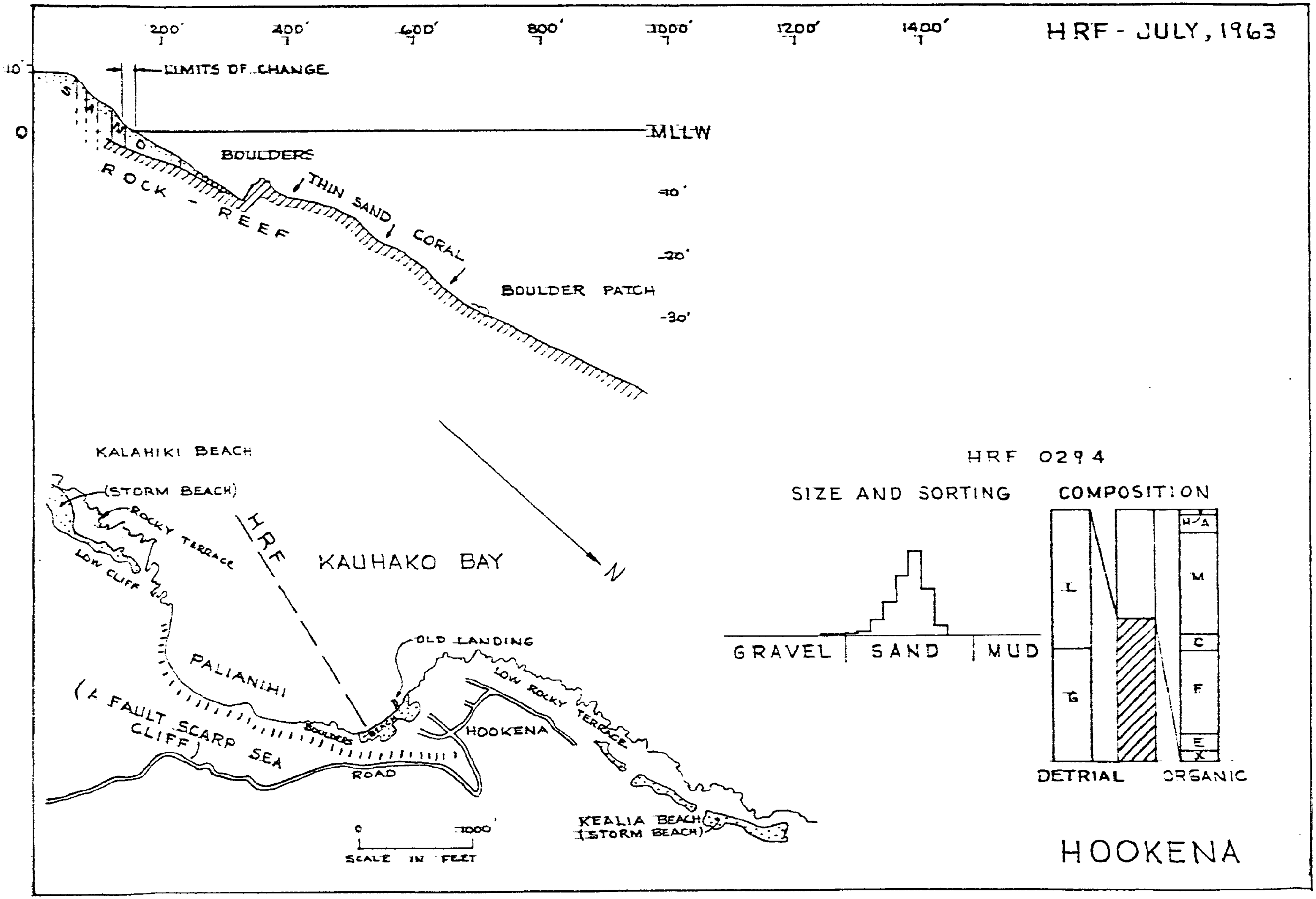
A prolific coral reef covers the surface of the rock.

Formerly there was a pocket beach of sand at Napoopoo on Kealakekua Bay, but the beach has been destroyed by erosion.

Disappearing Sands H-4. (Figure 86.) This beach lies south of Kailua Bay, along the Kona coast of the island of Hawaii. It is an arcuate pocket beach, 300 feet long. Because winter erosion completely destroys the beach, exposing only lava and boulders at the shoreline, it is popularly known as Disappearing Sands. During summer, a 2-foot thickness of sand covers the rock along the foreshore. This sand is a well sorted, medium-sized mixture of volcanic detritus in predominantly calcareous grains. A coconut grove occupies the backshore where sand is usually retained throughout the year.

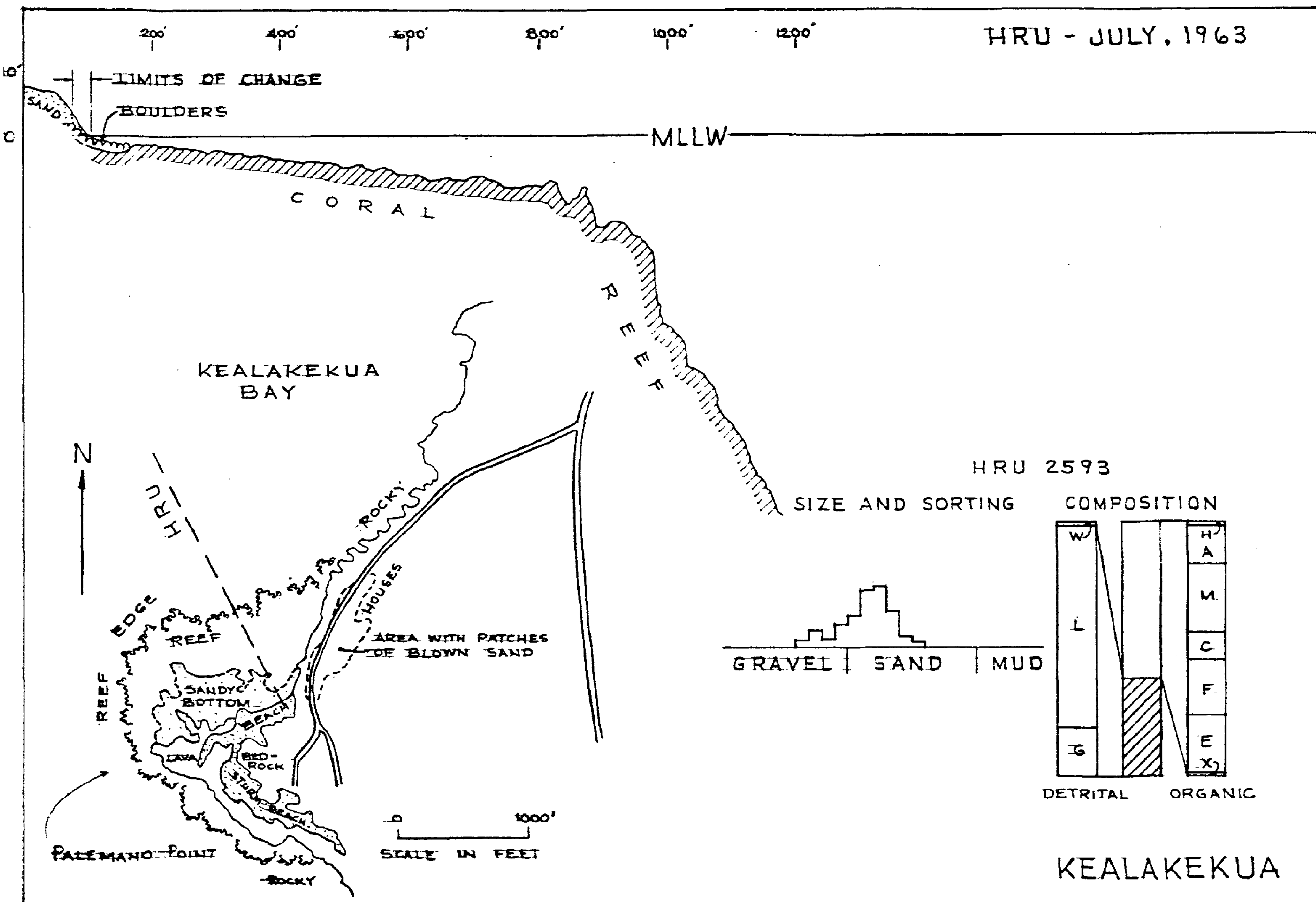
During the summer a thickness of up to 6 feet of sand lies offshore in a large sand pocket. This pocket probably serves as a repository for the eroded winter sand, although verification by measurement was impossible under winter wave conditions. Rock is exposed 700 feet offshore at a depth of 30 feet.

Hapuna H-4. (Figure 87.) Hapuna Beach lies along the northern sector of the western coast of the island of Hawaii, within Kawaihae Bay. This sector has most of the good beaches, of which there are but few on Hawaii. Hapuna is a long, straight beach, more than 1/2-mile in length, that reaches a maximum width of 210 feet during the summer. By early fall, however, the beach has eroded back more than 100 feet. Sand thickness in the summer is greater than 10 feet. Calcareous grains predominate in the well sorted, medium-sized sand. Both ends of the beach are bounded by points of lava. Grass and kiawe trees occupy the sandy backshore.



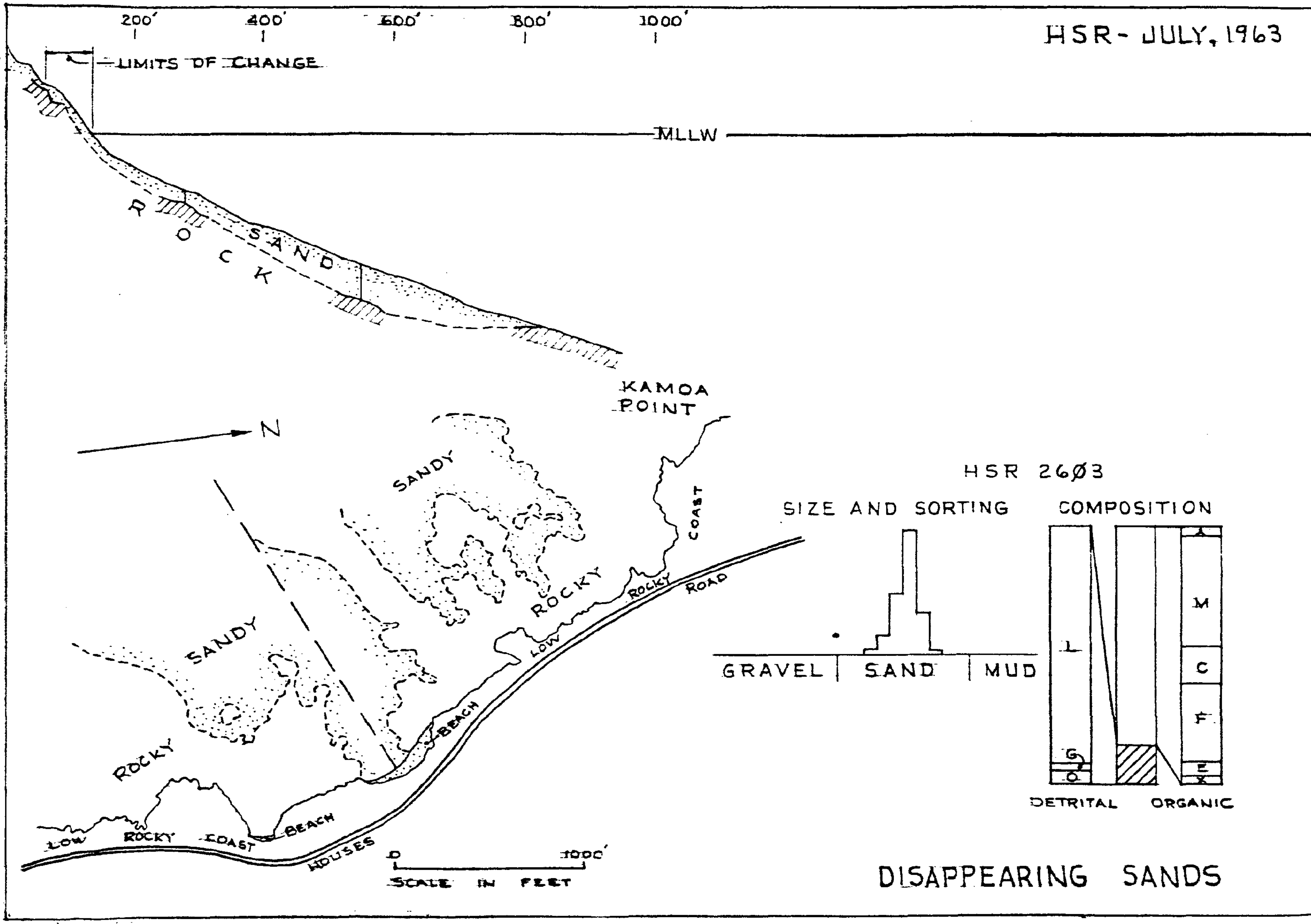
HRF - JULY, 1963
200'
400'
600'
800'
1000'
1200'
1400'
10'
0
-10'
-20'
-30'
LIMITS OF CHANGE
MLLW
S
H
W
O
BOULDERS
ROCK - REEF
THIN SAND
CORAL
BOULDER PATCH
KALAHIKI BEACH
(STORM BEACH)
ROCKY TERRACE
LOW CLIFF
HRF
KAUHAKO BAY
N
PALIANIHI
(A FAULT SCARP SEA CLIFF)
BOULDERS
BEACH
OLD LANDING
HOOKENA
LOW ROCKY TERRACE
ROAD
0
1000'
SCALE IN FEET
KEALIA BEACH
(STORM BEACH)
HRF 0294
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
I
G
H-A
M
C
F
E
X
DETRIAL
ORGANIC
HOOKENA

Fig. 84



HRU - JULY, 1963
200'
400'
600'
800'
1000'
1200'
LIMITS OF CHANGE
BOULDERS
SAND
MLLW
0
10
20
30'
CORAL
REEF
KEALAKEKUA
BAY
N
HRU
ROCKY
HOUSES
AREA WITH PATCHES OF BLOWN SAND
REEF
EDGE
REEF
SANDY BOTTOM
BEACH
LAVA
BED-ROCK
STORM BEACH
ROCKY
0
1000'
SCALE IN FEET
HRU 2593
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
H
A
M
C
F
E
X
DETRITAL
ORGANIC
KEALAKEKUA

Fig. 85


HSR- JULY, 1963
200'
400'
600'
800'
1000'
10'
0
LIMITS OF CHANGE
MLLW
0
10'
20'
30'
SAND
ROCK
KAMOA POINT
N
SANDY
SANDY
ROCKY
ROCKY
COAST
ROCKY
ROAD
LOW
BEACH
LOW ROCKY COAST
BEACH
HOUSES
0
1000'
SCALE IN FEET
HSR 26Ø3
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
L
G
O
M
C
F
E
X
DETRITAL
ORGANIC
DISAPPEARING SANDS
Fig. 86

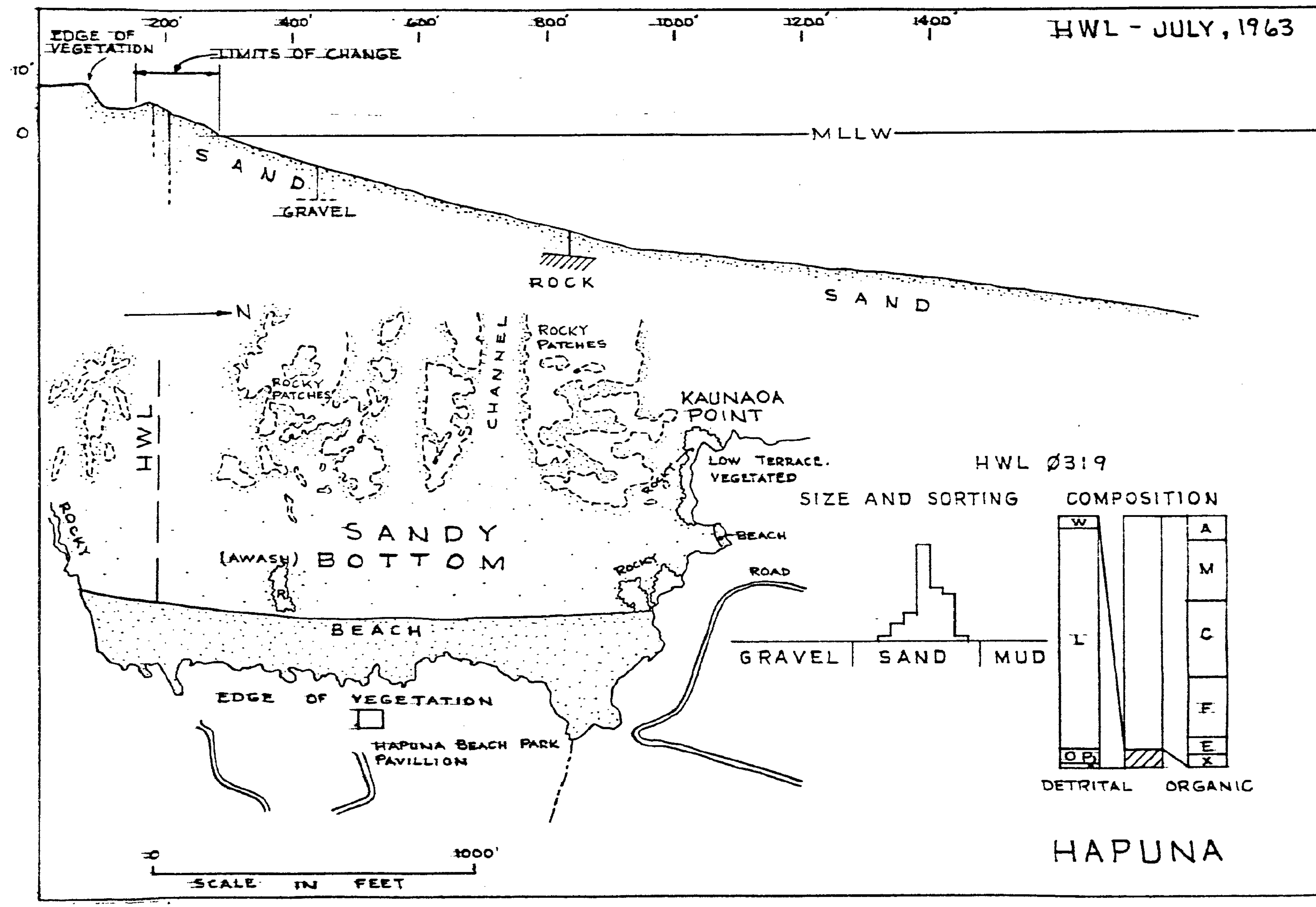

HWL - JULY, 1963
200'
400'
600'
800'
1000'
1200'
1400'
EDGE OF VEGETATION
LIMITS OF CHANGE
10'
0
MLLW
0
10'
20'
30'
SAND
GRAVEL
ROCK
SAND
N
ROCKY PATCHES
CHANNEL
ROCKY PATCHES
KAUNAOA POINT
LOW TERRACE. VEGETATED
HWL
ROCKY
SANDY
(AWASH) BOTTOM
R
ROCKY
BEACH
ROAD
BEACH
EDGE OF VEGETATION
HAPUNA BEACH PARK PAVILLION
0
1000'
SCALE IN FEET
HWL Ø3.19
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
O
P
A
M
C
F
E
X
DETRITAL
ORGANIC
HAPUNA

Fig. 87

Sand lies offshore in large pockets among coral heads. The sand is 3-1/2 feet in thickness at a depth of 15 feet.

The southern part of Hapuna Beach is used as a county park, whereas the northern part is a private beach park.

Kawaihae H-4. (Figure 88.) Kawaihae Beach at Spencer Beach Park lies within Kawaihae Bay near the northern end of the west coast of the island of Hawaii. The beach is essentially a 300-foot-long pocket beach held at each end by lava and beachrock, and throughout most of the year it is convex seaward. During the period of observation, its width varied from a maximum of 194 feet during the spring to a minimum of 134 feet during early fall, as a result of the erosion of this convexity. The sand is well sorted, medium-grained in size, and composed predominantly of calcareous fragments. Sand thickness at mean lower low water is 3-1/2 feet.

The sand thickness offshore is 2 feet out to 300 feet where a rocky surface, covered with algae and marked by numerous sand pockets, is exposed. Because of this long, shallow reef, waves arriving at the beach generally are small.

Pololu Valley H-5. (Figure 89.) The beach at the head of Pololu Valley on the northeast coast of the island of Hawaii is a 1200-foot-long straight beach, with a width of about 125 feet. The sand is a well sorted, medium-grain-size deposit, composed almost entirely of detrital grains that are fresh lava fragments. Sand depth at sea level is greater than 3 feet. In a period of one year, the beach has receded more than 100 feet. Cane pulp (bagasse) covers the entire beach, in some areas to a depth of almost 2 feet. Dunes occupy the entire backshore, their seaward edge having been cut into a low escarpment.

A shallow, sandy bottom continues past sea level for at least 250 feet, where the bottom commences to drop off much more rapidly. Because of this nearshore shallow area, during the summer, waves break offshore, delivering little energy to the beach itself and producing a gentle foreslope.

In the 1946 tsunami, Pololu Beach was eroded back to its underlying boulders by waves running up to a height of more than 50 feet. Quite possibly, the low escarpment in front of the dunes, mentioned above, was the limit of the 1946 erosion, and if so the beach has gained 125 feet in width since then.

Waipio Valley H-5. (Figure 90.) Waipio Beach lies at the mouth of Waipio Valley, the southernmost of the large valleys on the northeast coast of the island of Hawaii. The beach is 3/4-mile long, with a varying width averaging about 200 feet. In plan view Waipio Beach is slightly arcuate. The backshore area is covered with sand dunes.

The sand shifts to the southeast end of the beach during late fall and to the northwest end during early spring. Boulder beaches are thus exposed during the spring, summer, and early fall at the southeast end, and, during the winter, at the northwest end. There is only a small mixture of calcareous components in the medium-sized, well-sorted volcanic sand.

Generally, the offshore area is sandy for about one-fourth of a mile seaward. However, where the beach becomes a boulder beach, the nearshore area is also eroded to boulders. Nearshore currents are to the northwest during spring, and to the southeast during late fall. Waves are usually large at all seasons.

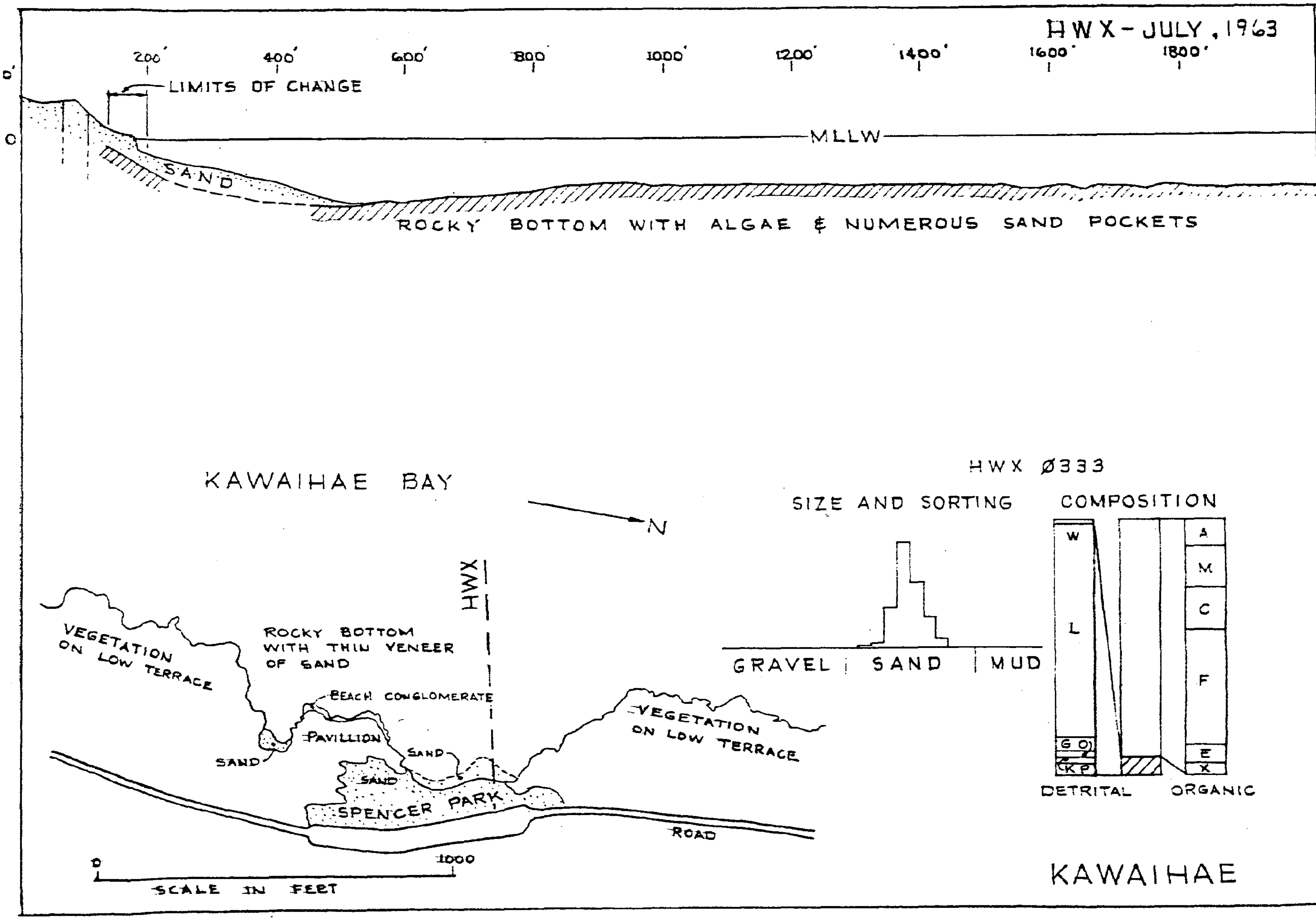
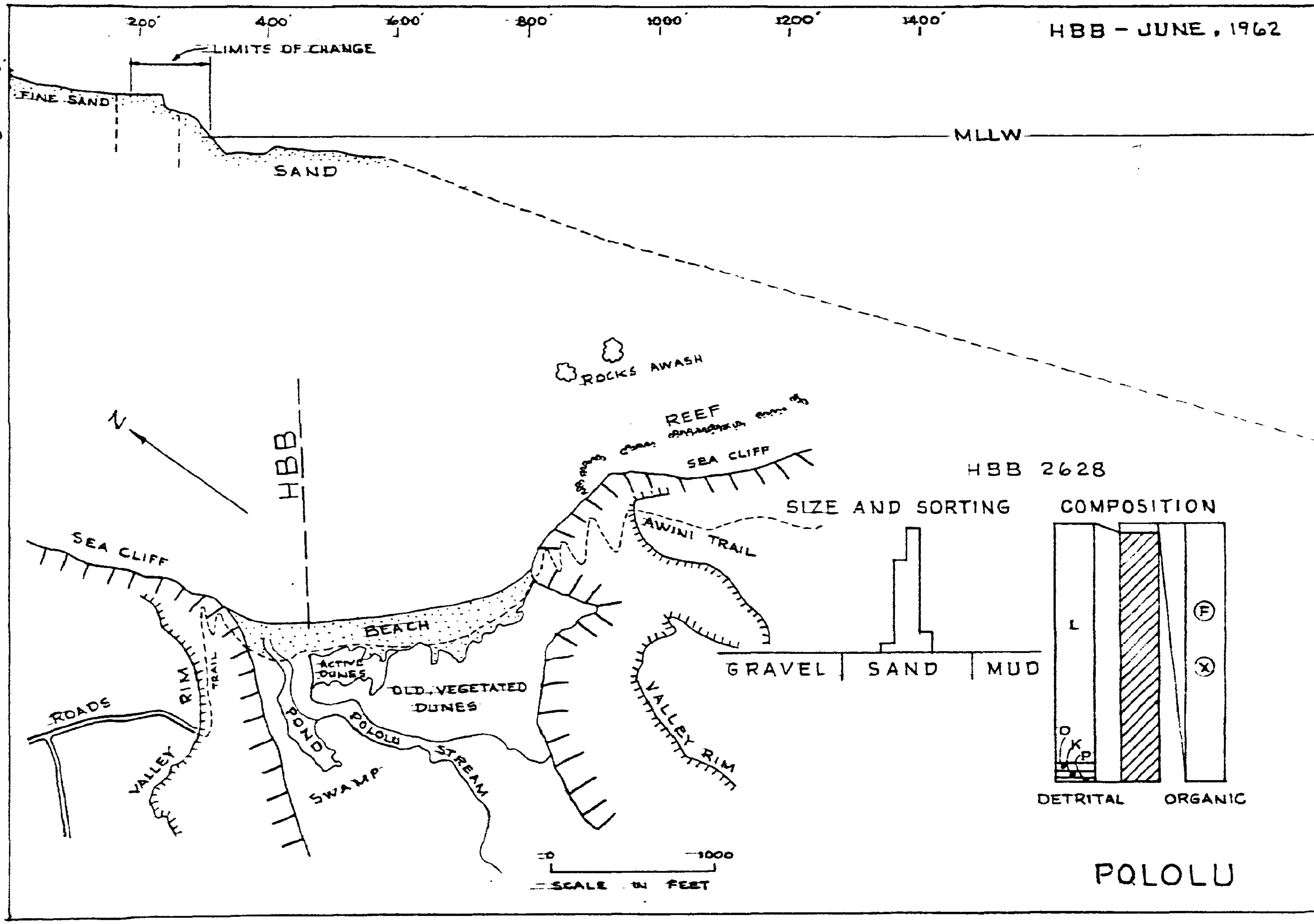

HWX - JULY, 1963
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
0'
0
LIMITS OF CHANGE
MLLW
0
10'
SAND
ROCKY BOTTOM WITH ALGAE & NUMEROUS SAND POCKETS
KAWAIHAE BAY
N
HWX
VEGETATION ON LOW TERRACE
ROCKY BOTTOM WITH THIN VENEER OF SAND
BEACH CONGLOMERATE
PAVILLION
SAND
SAND
SAND
SPENCER PARK
VEGETATION ON LOW TERRACE
ROAD
0
1000
SCALE IN FEET
HWX Ø333
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
W
L
G
O
K
P
A
M
C
F
E
X
DETRITAL
ORGANIC
KAWAIHAE

Fig. 88


HBB - JUNE, 1962
200'
400'
600'
800'
1000'
1200'
1400'
LIMITS OF CHANGE
FINE SAND
SAND
MLLW
0
10'
20'
ROCKS AWASH
REEF
SEA CLIFF
N
HBB
SEA CLIFF
AWINI TRAIL
BEACH
ACTIVE DUNES
OLD, VEGETATED DUNES
POND
POLOLU STREAM
SWAMP
TRAIL
RIM
VALLEY
ROADS
VALLEY RIM
0
1000
SCALE IN FEET
HBB 2628
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
L
O
K
P
F
X
DETRITAL
ORGANIC
POLOLU
Fig. 89

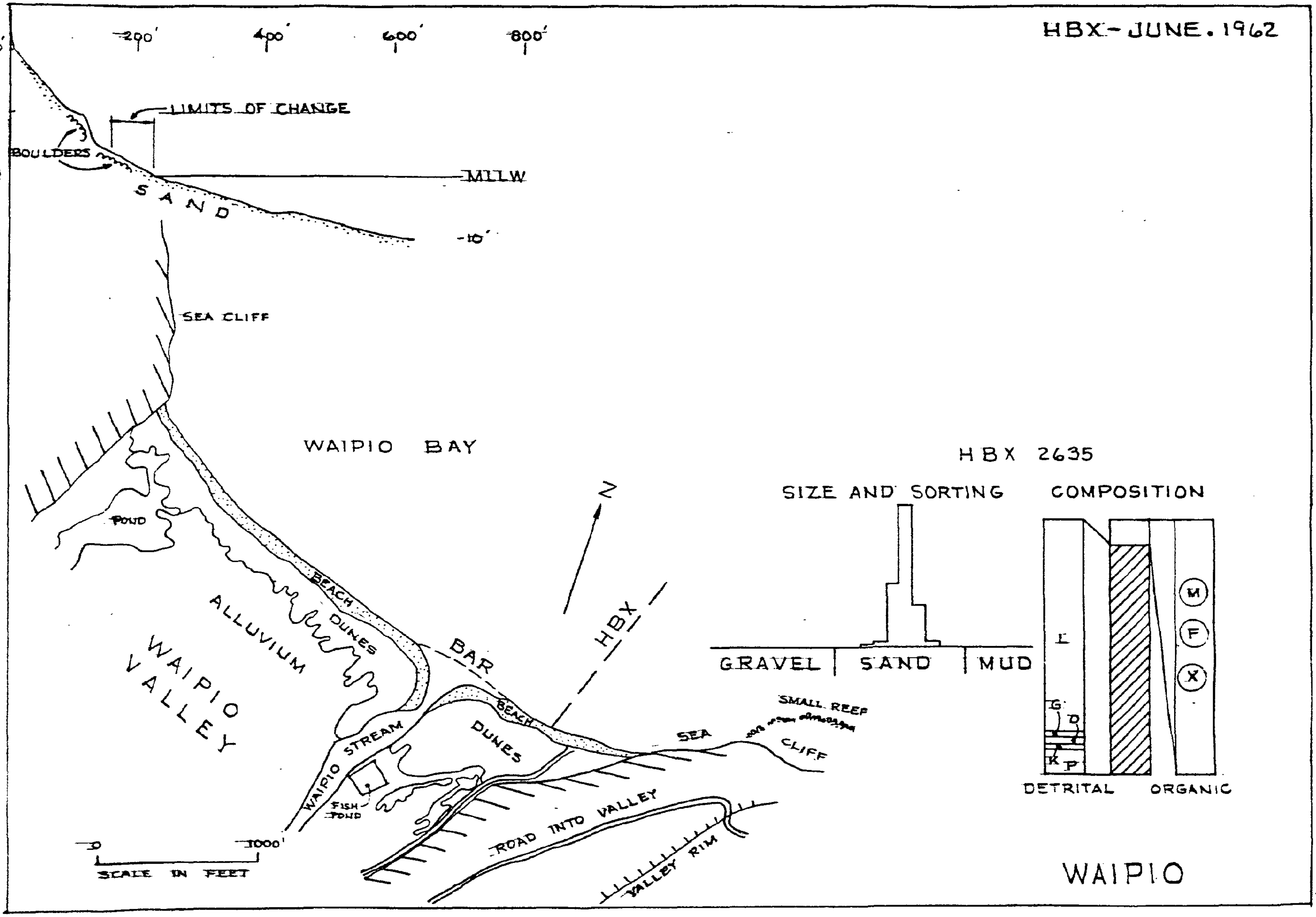

HBX - JUNE. 1962
20'
10'
0
200'
400'
600'
800'
LIMITS OF CHANGE
BOULDERS
MLLW
SAND
-10'
SEA CLIFF
WAIPIO BAY
POND
ALLUVIUM
WAIPIO VALLEY
BEACH
DUNES
BAR
HBX
N
WAIPIO STREAM
FISH POND
SEA
CLIFF
SMALL REEF
ROAD INTO VALLEY
VALLEY RIM
0
1000'
SCALE IN FEET
HBX 2635
SIZE AND SORTING
GRAVEL
SAND
MUD
COMPOSITION
DETRITAL
ORGANIC
G
D
K
P
M
F
X
WAIPIO

Fig. 90

SUPPORTING STUDIES AND SUMMARIES OF PREVIOUS INVESTIGATIONS

Coastal Geomorphology

General statement. Essential to analysis of landforms is an understanding of the composition and structure of materials being shaped, the geologic processes acting on those materials, and the changes through time of interaction between material and process.

Results of geological mapping of all the major islands have been published in a series of bulletins of the Hawaii Division of Hydrography. Essentially each of the Hawaiian Islands began as one or more volcanoes that were built from the deep sea floor by countless successive, thin intermittent extrusions of basaltic lava. Some other kinds of lavas erupted very late in the histories of some volcanoes. The volcanoes of the main islands include active Kilauea and Mauna Loa, dormant Hualalai and Haleakala, and several older extinct ones. Areas of these older volcanoes above sea level are being reduced by isostatic sinking, because these lava piles are a local load on the earth's crust, and by erosion. Locally the shoreline has been extended by secondary periods of volcanic activity by deposition of sediments at the mouths of streams, and by the growth of shallow-water marine organisms. Waves and currents constantly erode, transport and deposit sediment in the nearshore environment. Substantial changes in sea level in the most recent geologic past has modified many shorelines. The relationship to local geomorphology of each of these factors listed above is explained in somewhat more detail below. Factors important for other relationships may also be the topics of independent chapters of this report.

Materials and processes. The composition of basalt is a significant factor in the eventual coastal morphology of Hawaii. Essentially, basalt contains the minerals olivine, calcic plagioclase, and pyroxene augite, all of which decompose more rapidly in the weather than do most other rock-forming minerals. Weathering is especially rapid under our warm and humid tropical climate. Soil materials formed from basalt in the weathering zone include amorphous silica and alumina, and a variety of minerals--iron and aluminum sesquiocides, clay minerals, and so forth. The greatest part of the calcium, magnesium, and sodium, and much of the silicon in the basalt, is removed in solution after weathering. Because none was present initially and none formed during weathering, there is no quartz to become sand for Hawaiian beaches. Quartz grains of sand-size are overwhelmingly the dominant constituents of most of the owrld's beaches. The volcanic detrital components of our beaches, chiefly basalt that has not yet decomposed completely and locally, olivine or volcanic glass, are considerably less resistant to abrasion and solution on the beaches than is quartz. Materials removed from the land surface in solution, or in suspension as amorphous substances and as fine-grained clays, normally are not deposited in the nearshore environment, except where protected by reefs as along northern Lanai and southern Molokai.

Countless irregular joints in lava flows, clinkery aa surfaces, lava tunnels, and other primary basalt-lava structures allow fairly active marine erosion of exposed bedrock, attested by steep pali coasts on several islands. Relative activity of this erosion is in relation to geologic time, however, rather than in relation of our brief human experience. The irregularity of the structures reduces the likelihood of strong structural control of erosion, as is so evident on many coasts where the bedrock has a well developed joint or fault system. Like so many basalt coasts of the world, the sea cliffs may be very steep and high.

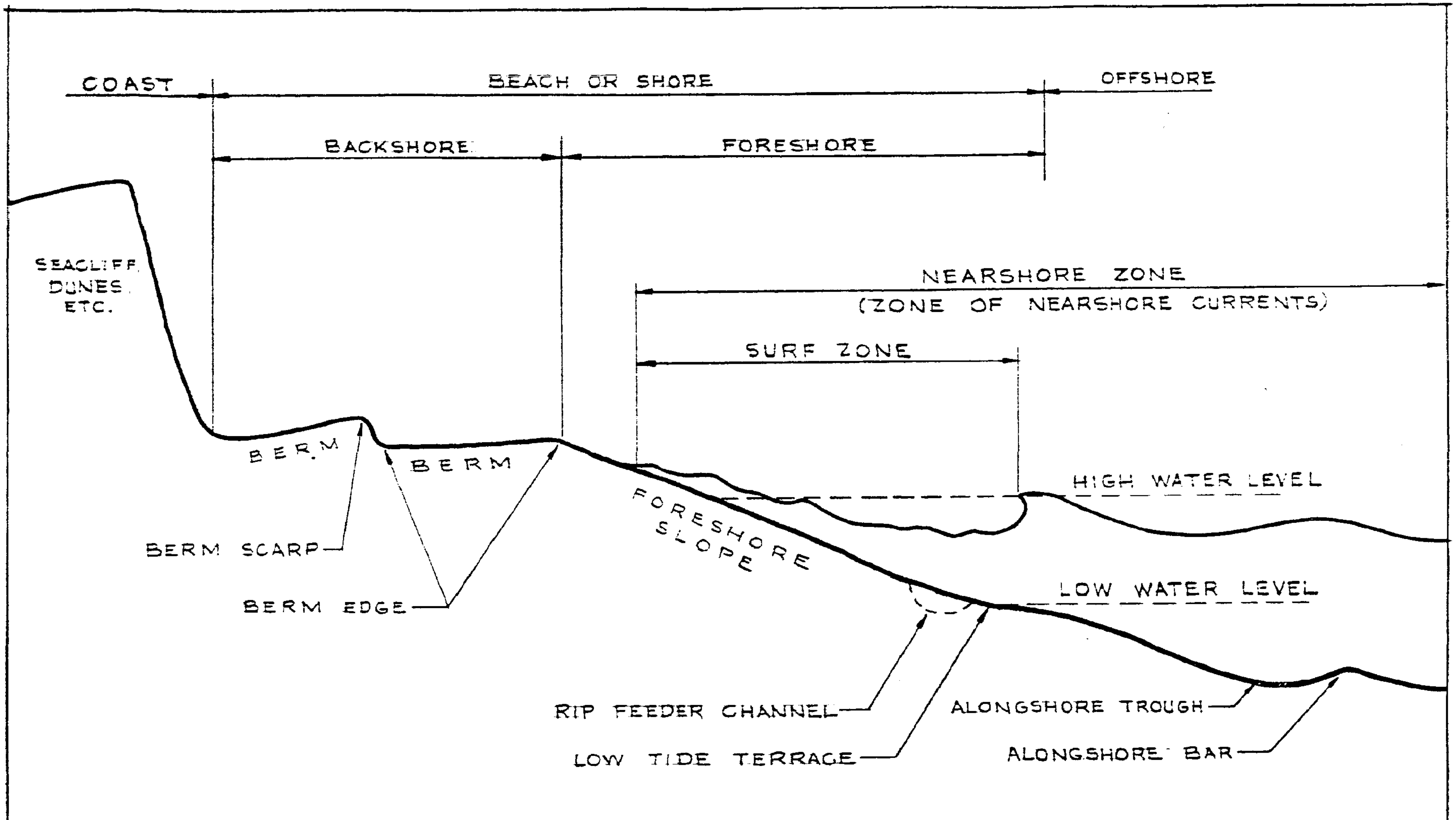
Late in the histories of some volcanoes, lavas that are more siliceous than basalt may be extruded from the central vent and the rift zones. These flows are usually thicker than the underlying basalts, and may be more resistant to chemical weathering as well. For these reasons this type of late flow acts as an armor for the more easily eroded basalt beneath it. A few volcanoes have an even later episode of intermittent volcanism from scattered vents on the eroded flanks of the main volcanoes.

The products of weathering are removed by streams and the large grains are deposited where the streamflow slackens as it enters the ocean, forming such geomorphic forms as bars, barriers, and deltas. On coasts exposed to moderate wave action the sediment is worked back and forth in the shallow water and on the beaches, commonly forming submerged bars or exposed barriers at the stream mouths. The sediment accumulation at the mouths of streams which enter the sea on coasts protected by reefs are small deltas. This particular geomorphic form is evident along the shores of Kaneohe Bay, Oahu, of south Molokai, and of north Lanai, commonly in association with mangrove growth. Sediment may drift away from stream-mouth sources along the shore in response to nearshore currents, forming beaches, shallow-water sand patches, and ridges of sand and gravel.

By-products of biological activity in shallow waters frequently include the hard skeletal parts of organisms that remain as solid structures or as sediment, even after the plant or animal dies and the soft, living tissues decay. The solid structure may become sufficiently massive and extensive, through years of continuing growth, to warrant the term reef. Corals and red (corralline) algae are the chief contributors to the framework of local reefs, and gravel, sand and mud from fragments of these and other organisms add bulk to the reef by filling in between coral heads.

Hawaii's reefs are of the fringing variety; only in the case of Kaneohe Bay Oahu, are there barriers with a deep lagoon between reef and shore. Shallow, broad reefs are most extensive off north and northeastern Kauai, Oahu from Kaena Point clockwise to Barber's Point, southern Molokai, northern Lanai, and southwestern and nort -central Maui. In but few of these areas, however, is coral growth very vigorous at the present time, when compared with coral growth around atolls and islands of tropical areas of the West Pacific, Indian Ocean, Red Sea, and Caribbean Sea. Deeper reefs, with even less active coral growth today, are common off the western sides of most islands. The most flourishing thickets of live coral are commonly found on the submarine surfaces of fairly recent lava flows.

The reef environment is the habitat of a variety of organisms with shells or other hard parts, chiefly of calcium carbonate. These skeletons, or fragments of them become part of the nearshore sediment. Carbonate sand formed on the reefs may be mixed in any proportion with sand worn from the land by erosion of its volcanic rock. Sediment in nearshore areas is transported and shaped by water and wind into various geomorphic forms. Conspicuous among these, and the object of most interest, are beaches, but also included are dunes, bars, and sand patches. The shape of local beaches with their characteristically steep foreshores and common lack of berms (Fig. 91), appears to be dependent on the coarse nature of local carbonate and volcanic sands in contrast to the finer-grained quartz sands of most beaches of the world.



BEACH PROFILE - RELATED TERMS

Fig. 91.

Local cementation of sediment is important to an understanding of coastal geomorphology, as the resultant sedimentary rock is more resistant to erosion than is adjacent unconsolidated sediment. Most of the Hawaiian eolianites, or lithified dune sands, seem to have been formed in the Ice Age, or Pleistocene epoch of Geologic Time, immediately preceeding Recent Time a few thousand years ago. However, much of the local beachrock, which results from the cementation of sand at sea level, is being formed at the present day.

Changes with time. One of the most basic factors in Hawaiian coastal geomorphology is the relative age and position of the individual volcanoes. The broadly lobate coasts that characterize recent volcanic activity have but few reefs or beaches, and have even-sloped submarine profiles. Overlapping lobes of adjacent volcanoes leave broad bays between them. Coasts of older volcanoes that are more deeply dissected by streams and worn by the surf are more irregular in outline. The most irregular coast in these islands is that of southeastern Oahu, where a series of late-stage volcanic eruptions has superimposed younger tuff cones and lava flows on the eroded bedrock, and where reefs, now elevated to coastal plains, were common in the Pleistocene.

Isostatic sinking of the Islands is very slow, with no possibility of damage to property. Shallow-water corals probably of Miocene age, perhaps 15 million years old, were dredged from a 300-fathom terrace several miles south of Honolulu, suggesting an average rate of subsidence of about one foot in 8000 or 9000 years.

The more rapid changes in the relative positions of sea level have been due to eustatic, or world-wide, changes in the volume of sea water in the oceans in the immediate geologic past. During the Pleistocene, or Ice Age, at times of glacial advance on the continents, the immense volumes of water frozen into glacial ice lowered sea level by 300 to 450 feet. Conversely, in interglacial times warmer than the present, when the Antarctic and Greenland ice caps were melted, sea level was about 100 feet higher than it is now. These events were repeated several times in the past 500,000 years. Most of the world-wide evidence suggests that the most recent history of sea level involved a rise of perhaps 300 feet, starting about 14,000 years ago and ending near present sea level about 5000 years ago, and that the level has been gently fluctuating since then. In the past 100 years sea level around the world has risen an average of 8 inches, as glaciers have melted fairly rapidly. Meteorologists, paleoclimatologists, and marine geologists are uncertain in their guesses about the climate of our immediate future, and so we cannot predict the rise or fall of our local sea level. In any event, it would not be rapid enough to cause any danger whatsoever to our inhabitants. However, there is a possibility that over a period of several decades or a few hundred of years shorefront property may either be enlarged slowly by sea level sinking, or be reduced in area by a rise of water.

Waves, Currents, and Other Energy Sources: by T. Chamberlain

Sources. The seasonal and annual shifting of sand along the coasts of the Hawaiian Islands, the movement of sand on and off shore perpendicular to the coasts, in short, any behavior of sediment or water in the nearshore or coastal zone, are a result of some force doing work. Therefore, if we desire to understand the beaches and coasts of the Hawaiian Islands we should first look at the sources and amounts of energy (since energy is the ability to do work) that are available.

It is not yet possible to describe qualitatively the various energies reaching the coasts of the Hawaiian Islands, nor is it yet possible even to identify all of the energy sources themselves. However, the major forces can be described and a relative position of importance can be assigned for each. The following sources, in decreasing order of importance, are responsible for most of the energy found in the nearshore zone of the Hawaiian Islands:

1. Ocean waves (waves generated adjacent to or a considerable distance from the Hawaiian Islands and arriving in the near-shore zone either as sea or swell)
2. Unidirectional water movements (oceanic currents generated in adjacent areas by windstress, water-density differences, tidal forces, ocean waves, etc.)
3. Atmospheric winds
4. Tides
5. Tsunamis

Not all of the energy reaching the coast of the Hawaii Islands is available for transporting sand and for changing the shape of the beaches. Some of the various ways this energy is dissipated once it reaches the nearshore zone can be summarized as follows:

1. Reflection from the beach
2. Generation of waves within the nearshore zone (surf beat, internal waves)
3. Generation of nearshore currents
4. Generation of heat (turbulence, bottom stress, percolation)

5. Generation of noise

6. Generation of microseismic tremors

7. Transportation of sediment

Ocean waves. Almost all of the energy that is available along the coasts of the Hawaiian Islands, for deforming the beaches and transporting sediment, arrives in the form of ocean waves. These waves are generated in all parts of the Pacific Basin, some even in the South Indian Ocean, and, after a complex history they arrive in the Hawaiian Islands exhibiting a wide variety of heights, lengths, and periods. At any one time several generating areas may be supplying waves simultaneously, and this consideration along with the seasonal activity of certain generating areas, the interaction of various wave trains, the attenuation of waves over long distances, and the effect of local winds on distantly generated waves, all result in a very complex wave pattern along the coasts of the Hawaiian Islands.

Although a complete statistical analysis of the waves arriving in the Hawaiian Islands is not yet possible, a general description of the prevailing wave conditions can be given. It is suggested, from a review of available wind and wave data, that the entire wave spectrum in the Hawaiian Islands can be reduced to a few generalized wave types, typified by specific wave heights, lengths, and periods, and related to deduced wave-generating areas through the means of meteorological observations.

1. Northeast Trade Waves. The waves generated by the northeast trade winds are the most persistant wave-type along the eastern shores of the Hawaiian Islands. They may be present all year, but are largest

during the late spring, summer, and early fall months. They approach the coasts from the northeast and range in height from 4 to 12 feet, and in period, from 5 to 8 seconds.

2. North Pacific Swell. These waves are generated by intense winds associated with the winter low-pressure areas south of the Aleutian Islands. They are generated in the Gulf of Alaska or in the mid-latitudes of the North Pacific, generally in late winter or early spring. They may approach from the northwest, north, or northeast and have heights of 8 to 14 feet and periods of 10 to 17 seconds. Some of the largest waves reaching the Hawaiian Islands are of this type.

3. Kona Storm Waves. These waves are generated by strong winds associated with the passage of low pressure zones into the Hawaiian region. The winds, and therefore the waves, may vary greatly in direction, but generally waves from the southwest quadrant are most common and can usually be expected during the late winter and early spring months. Heights range from 10 to 15 feet and periods range from 8 to 10 seconds.

4. Southern Swell. During the summer months extremely long, low waves reach the Hawaiian Islands from generating areas in the Antarctic region. Typical waves have heights of 1 to 4 feet and periods of 14 to 22 seconds, and they approach from the southeast, south, or southwest. On the southern and lee sides of the Hawaiian Islands, southern swell is the most persistant wave-type.

Unidirectional water movements. The Hawaiian Islands are located in that portion of the Pacific Ocean which is dominated by the North Equatorial Current. This current, caused by the Northeast Trades, and setting to the west, establishes the general drift pattern for the entire area. Local currents around the various islands of the Hawaiian Group are either eddies related to the effect of the islands upon the North Equatorial Current or are tidal currents; in deeper water, the North Equatorial Current eddies predominate, whereas, in the shallow water of the island shelves, tide-generated currents are most conspicuous.

Along the shores of the Hawaiian Islands tow interrelated current systems can be discerned. An outer system called the Coastal Current System is conspicuous on the island shelves and as far shoreward as the reef edges. This system is quite complex and is controlled by submarine topography coastal configuration, and the direction and magnitude of the tidal currents.

Inside the reefs and along the beaches a secondary or Nearshore Current System is present which is intimately connected with the Coastal System. This Nearshore Current System is mainly generated by the mass transport of water associated with the passage of waves, although coastal tidal currents may have some effect upon the Nearshore System.

The circulation within the nearshore system consists of the onshore mass transport of water, an alongshore transport (alongshore currents), and a return flow seaward (rip currents). The position along the coast of the various components of this nearshore system depends considerably upon bottom topography, particularly the position of sand channels through the reef edge and across the reef flat.

Both the Coastal System and the Nearshore System are important in the erosion, transport, and deposition of coastal sediments. Sediments produced on the outer reefs are transported by these current systems across the reef and sand placed in suspension within the surf zone is circulated via these current systems alongshore to various positions on the reef, or offshore into deep water.

Atmospheric winds. The atmospheric winds, especially the persistant Northeast Trades and the Kona Winds, are important energy sources along the coasts of the Hawaiian Islands. Generally from April to November the Northeast Trades blow daily with average velocities of about 10 to 20 miles per hour from the northeast or east. By means of these winds vast quantities of beach sand are blown inland in the form of dunes and are permanently lost to the nearshore zone. Good examples of the important effects of these winds can be seen along the Moomomi coast of Molokai and along the north and northeast coasts of Lanai, especially in the area between Palahinu and Pohakuloa Points.

From November through March, Kona winds, frequently with velocities in excess of 25 miles per hour, can be occassionally anticipated from the west, southwest, or south. However, the less persistant nature of these winds makes them less effective in the movement of coastal sand.

Tides. The Hawaiian tide is of a mixed nature a diurnal and a semi-diurnal component being usually discernable. The tidal curve is characterized by a small range of tidal height, usually less than 3 feet, and by the occurrence of two unequal high tides per tidal cycle. The tidal wave approaches the Hawaiian Islands from the nort -northeast and progresses toward the south-southwest. The ebb current is reversed to the north-northeast.

Although large amounts of energy are contained in the tides, little of this energy is directly available from the transportation of sediment.

The tides probably play their most important role in shifting the surf zone back and forth across the beach face, thereby exposing a wider coastal zone to the effects of the waves. Most of the tidal energy arriving in the Hawaiian Islands is probably utilized in the generation of the tidal currents making up the Coastal Current System as discussed above.

Tsunamis. Tsunamis are an infrequent source of very high energy along the coast. They are discussed below in the section on natural disasters in shoreline areas.

Origin of Sand

Light sand versus dark sand. Sand in the shoreline areas of Hawaiii is composed of two general types of grains mixed together in proportions that vary from one locality to the next. Light-colored grains that are calcareous in nature contrast with dark-colored grains. This gross color difference is correlated with a genetic difference in that the light-colored grains are organic or biological in origin, the fragments of skeletal parts of certain invertebrate animals and algae that lived and died in the sea. Some other terms that have been used for this type of sand are lime-sand, carbonate sand, and coral sand. On the other hand, the dark grains have originated from the land through weathering processes. The detritus washed down into the sea has thus had chiefly a physical origin. Some names that have been used for this sand are terrigenous sand, detrital sand, silicate sand, and volcanic sand.

Therefore, some sand forms in shallow marine waters from organisms that lived there, and some forms inland from the weathering and erosion of bedrock. A fairly s mple method of determining the proportion, by weight of each in a particular sand is to dissolve the calcareous grains of a weighed sample in hydrochloric acid and then to weigh the washed and dried insoluble residue. About 1000 Hawaiian samples have been treated by this method, and the results from one sea-level sample is illustrated for each of the 90 significant beach systems reported upon in this paper. Generally there is a high proportion of calcareous grains along coasts with reefs, and on the west sides of islands. Detrital grains are most abundant off the mouths of streams. For the State as a whole, Oahu Island has the most calcareous sands and Hawaii Island the least.

Detrital components. The insoluble residues were examined under binocular and petrographic (polarizing) microscopes in order to establish the composition of the terrigenous portion. The results for samples from the 90 selected beaches are shown in this report. In a few Molokai and Lanai samples some grains are finer than sand-size (i.e., less than 0.062 mm). These muds include clays, iron-oxide accretionary bodies, and silt too fine to identify optically.

The remaining grains of sand (rarely of gravel size) are from pre-existing bedrock, either fragments of rock itself or fragments of specific minerals from rock. The rock fragments are all volcanic in origin. For the purposes of this study, three types of lithic grains, which actually intergrade into one another, were distinguished. Some grains are more or less altered by chemical weathering, some grains are of fresh microcrystalline lava, and some are of fresh volcanic glass. Fresh lave grains are the most abundant lithic grains in most samples. Of these fresh lava grains, the basalt grains predominate except in some East Molokai, Maui, and North Hawaii sands where there are lighter-colored grains, probably from the lava rocks mugearite and hawaiite. Glass grains are most abundant near recent eruptions where they make the so-called "black sand" beaches, as on the southern coasts of Hawaii Island.

The monomineralic sand grains were originally phenocrysts, i.e., cystals of larger size than the groundmass-size of other mineral crystals, in lavas. Most common in Hawaii by far, both in the parent rock and in sands, is olivine, a ferro-magnesian silicate mineral. Black grains of magnetite and ilmenite (iron and iron-titanium oxides) and of augite (a calcium-bearing ferromagnesiam silicate)are common only locally. Quartz and the potash feldspars, the most common minerals of sands in most places of the world, are absent here.

The distribution of detrital grains of sand along the shores of the Hawaiian Islands follows very closely the bedrock geology of the hinterlands, as is revealed in the detailed maps and reports of the series of Bulletins of the Hawaii Division of Hydrography (Stearns and Vaksvik, 1935, through Macdonald, Davis, and Cox, 1960).

Calcareous components. Special efforts were made to identify the components of the calcareous grains, because of the general lack of information on lime-sand in Hawaii and elsewhere, and because most of the important beaches of the State are highly calcareous. Two students, A. Kranek and L. D. Baver, Jr., independently examined samples several months apart, and because their results were closely compatible it is believed their results are significant. The initial work, including most of the testing of a variety of techniques, was by Miss Kranek, and the later work involving a larger number of unknown samples, was by Mr. Baver. The following descriptions refer chiefly to the final methods used.

In each instance the first part of the study was an eximination of skeletal material of known invertebrate animals and marine algae that live in shallow waters and were assumed to contribute to the sand. For example, among corals, Pocillopora, Porites, and Montipora were included because of their abundance in Hawaiian waters. Identified specimens of these coral genera were crushed with a sledge hammer until the fragments were in the range of sand size (between 2.0 and 0.062 mm). The sand grains of each coral were then abraded in a jar mill for periods of time from 6 hours to 6 days. After abrasion, the sand was washed, sieved, and studied. Porites and Montipora grains could be identified as fine as fine-sand size (to 0.125 mm). In grains less than 0.125 mm the characteristic porous structure was lost. Pocillopora was difficult to identify except on edges of the coral head, and abrasion increased the difficulty. Known echinoid tests and spines, mollusk shells, and calcareous algae were abraded and studied in a similar manner.

Areas of active coral and algal growth were studied by skin and SCUBA diving, and offshore sand samples from these areas studied. Familiarization with the known biota was beneficial in the subsequent identification of the unknown sand grains.

Selective staining was a further aid in identification. There are two common mineral forms of calcium carbonate, and some living organisms precipitate their skeletal tissues from the polymorph calcite, others from the polymorph aragonite, and still others from layers of both. Aragonite, but not calcite, is stained gray to black by Feigl's solution, whereas calcite is not affected (Warne, 1962). Corals, the green alga Halimeda, and mollisks contain aragonite, but formainifera, red algae, and echinoids contain calcite (Chave, 1954a; Lowenstam, 1954; Revelle and Fairbridge, 1957); therefore the former stain, and the latter do not. An exception in a very few samples was that Feigl's solution did not stain aragonite grains coated with a red-brown or pinkish color from iron-oxide-rich muds.

In practice the operator obtained a random split of the main sample with a micro-splitter. The split fractions were placed into coded test tubes, stained by immersion for one minute and fifteen seconds in Feigl's solution, and dried at 25°C.

Each operator approached the problem of the conversion of observed and identified grains to colume percentage of compositon in a slightly different way. One operator mounted grains from the sieve containing modal grain size, and counted grains intercepted on systematic traverses of the microscope slide. As the grains were all nearly the same size, this type of counting would approximate the volume of components in the modal size. The chief bias is that there may be some sorting of components by size. For example, a smaller grain that is solid and well-rounded (perhaps an echinoid fragment) may have the same hydraulic behavior as a larger, porous, disk-like grain (perhaps a foraminifer).

The second operator used a split of the entire sample and a modification of the point-count method of Chayes (1949) to approximate the compositional volumes. There is good correlation if the sample is well-sorted or if the grain shapes are not greatly different from spheres. Otherwise the count becomes biased in favor of the smaller oddly-shaped grains.

A series of 400 or more points was counted on most samples. Some samples with predominantly detrital grains had fewer than 400 points of carbonate grains identified on them. After a few weeks each slide was counted a second time. These point counts ranged from 200 to 300, depending on the correlation with the first 400 count. Where the first and second count differed, the second count was assumed to be the better because of experience gained in identification.

Some samples selected were too fine-grained to be identified, and in those cases samples from the same location at different seasons (usually winter) that were coarser grained were used. It was assumed that the identification of the coarser sand was representative of the beach, and that the finer-grained sample would have approximately the same percentages of constituent particles, if they could have been identified. Actually, some grains which characteristically are of a single size, such as whole foraminifera, may have been discriminated against by this method of substituting coarser samples.

About 100 samples were examined by Miss Kranek, and 170 by Mr. Baver. Results were closely comparable in nearly all instances where the same sample was examined by both operators. The samples for 90 significant beaches, illustrated in this report, were among Baver's work.

Components identified are the calcareous green alga Halimeda, red or coralline algae, mollusks (no attempt was made to separate gastropods from pelecypods), coral, foraminifera (shelled, amoeba-like one-celled animals) sponge spicules, echinoids (sea urchins), and arthropods (crabs and ostracods).

On Kauai foraminifera predominated, followed strongly by red algae and mollusks. Echinoids, some coral, and even less Halimeda completed most samples. Oahu's calcareous sands are rather similar; foraminifera again most abundant, followed by mollusks and red algae, and more sparsely by echinoids, Halimeda, and coral. On Molokai and Lanai the proportion is the same as for Oahu.

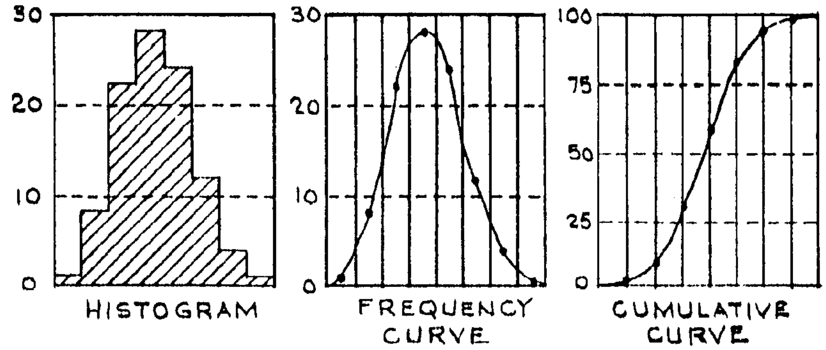
The same order follows on Maui where foraminifera are closely followed by mollusks, with red algae and echinoids in moderate abundance, trailed by coral and rare Halimeda. On Hawaii, mollusks and foraminifera are the most abundant components of lime-sand, with coral third in abundance. Echinoids and red algae are subordinate and Halimeda rare.

For the Islands as a whole, therefore, it is rather a misnomer to speak of "coral sand," as coral is a poor fifth behind foraminifera, mollusks, red algae, and echinoids. Only Halimeda, so important in the Bahamas and the Western Pacific atolls, and insignificant amounts of sponge spicules, ostracods, crabs, and similar rare components, are less abundant here than coral. Of course the coral skeletal material, helped by encrustations of red algae, provides the framework of the fringing reefs whereon live the foraminifera, mollusks, and echinoids.

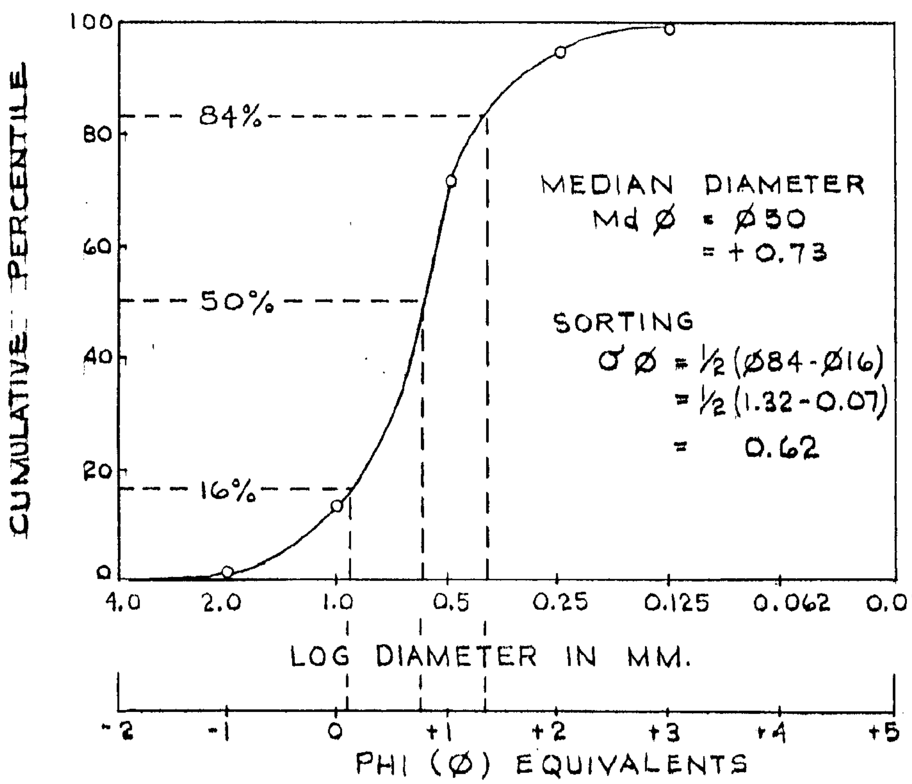
Sand on the Beaches

Grain-size parameters. To date about 1100 sediment samples collected from the shoreline areas of the six largest Hawaiian Islands have been analyzed for grain-size distribution. These mechanical analyses, as they are sometimes called, were performed by shaking in a nest of graded sieves a random split of each particular sample. The weight percentage of sample that did not pass through a certain size of sieve openings was recorded, and could be displayed graphically in histograms, as shown in this report for 90 significant beach systems, or in a cumulative curve (Fig 92).

GRAPHIC REPRESENTATION OF SIZE DISTRIBUTION DATA



SIZE DISTRIBUTION OF PARTICLES GRAPHED IN THREE WAYS



DETERMINATION OF MEDIAN DIAMETER AND SORTING FROM THE CUMULATIVE CURVE

Fig. 92.

The 50% point on the cumulative curve is the median grain size of the sample: half of the sample's weight is of grains coarser than that size and half is finer (Fig 92). The median grain size of a sample is a function of the initial size of the grains transported to the depositional site and of the wave energies that act on the sediment. For example, one would never expect to find a gravel of foraminifera or of olivine, because neither living foraminifera nor olivine phenocrysts are more than a few millimeters in original size. Also, coarser-grained sediments will be in equilibrium on beaches with strong waves, and finer-grained sediments on beaches with weaker waves. Size is described in phi (ϕ) units, the negative logarithm of the grain size in millimeters.

A second parameter useful in describing a sediment is its sorting, or tendency for the grains to be nearly the same size. One or two high bars on a distogram or a nearly vertical cumulative curve show good sorting, as illustrated for Fleming's and Makaha beaches (Fig 28 and 79). A numerical expression of sorting can be obtained by comparing the sizes of the 16th and 84th percentiles (Fig 92). Sorting of any particular sample is a function both of its inheritance and its environment. The delta deposit of an intermittent stream, for example, might be a poorly sorted mixture of gravel, sand, and mud. After a sediment reaches an area of deposition it may be sorted by waves; the sand moved from the pebbles by waves of a particular size, and the mud carried away in suspension.

Two additional parameters used to describe sediment can also be calculated from the mechanical analysis. Skewness is the tendency away from symmetry of the histogram caused by either coarse or fine admixtures.

Kurtosis is the tendency toward a sharp peak on the histogram. These two parameters are useful in comparing sediment from one geomorphic environment to that of another geomorphic environment, as beach versus dune. Skewness and kurtosis were also determined for the 100 samples, but were little used in this discussion.

Effects of location and season. Samples were collected both from the beach ranges which were remeasured quarterly and from spots at random from the shoreline between ranges. The following table shows the average grain-size for samples from each island, by quadrant and overall.

TABLE 1. Average Grain Size (Phi-median) of Hawaiian Beach Sand, by Island and Quadrant of Exposure.

		N	E	S	W	All
Kauai						
1.	No. samples	77	45	37	24	183
2.	Average median diameter, ø	1.38	1.70	1.49	1.43	1.5
Oahu						
1.	No. samples	76	153	39	56	324
2.	Average median diameter, ø	.69	1.51	.83	1.03	1.2
Molokai						
1.	No. samples	45	14	88	60	207
2.	Average median diameter, ø	.92	1.81	.82	.84	0.9
Lanai						
1.	No. samples	28	0	9	0	37
2.	Average median diameter, ø	1.4		1.7		1.5
Maui						
1.	No. samples	66	30	124	44	264
2.	Average median diameter, ø	1.52	2.24	1.93	1.37	1.8
Hawaii						
1.	No. samples	18	10	16	50	94
2.	Average median diameter, ø	1.89	.81	.31	1.60	1.4

It can be seen that many beaches of Molokai have coarse sand (small phi or Ø values) and that many on Maui have fine sand. Of greater interest is the general, fine grain-size of beaches facing the east, with the exception of those on Hawaii Island. Probably this is due to the high trade wind-controlled rainfall along windward-coast hinterlands which allows for deep chemical weathering so that mainly fine-grained detritus is formed and transported to the shore.*

Coarse sands (low Ø values) for many north and west coasts probably reflect the strong, winter swell-generated surf on those coasts.

A division of the coasts on the basis of their exposures showed the relation of sediment grain size and sorting to the local geomorphology. In Table 2, "Reef" is shallower than 10 feet at 500 feet from the beach, "Open" is deeper than 30 feet at that distance, and "Intermediate" is in between. Also listed are "Bays," including large artificial harbors, and "Deltas," at stream mouths with a large supply of detrital sediment.

TABLE 2. Average Grain Size (Phi-median) and Sorting of Hawaiian Beach Sand, by Geomorphic Setting

	Reef	Intermediate	Open	Bays	Deltas
Number of samples	394	184	363	96	42
Average median (Ø)	1.26	1.39	1.35	1.94	1.48
Average sorting	.66	.49	.46	.71	.71

* Inman, Gayman, and Cox (1963) proposed the lack of detrital grains northeast coasts in general to that intense weathering.

The fine-grained sediments in bays are not winnowed out by strong wave action. The sorting figures show a close correlation between wave action and sorting from the well-sorted sands of open coasts (low numbers) through intermediate and shallow-reef environments, to the protected bays. The deltas also have poor sorting. The stream-supplied sediment of various grain sizes is deposited at a rate faster than it can be reworked by the waves.

The increased coarseness of sand on beaches in the winter is shown by the low median ϕ values in the next table. The range varies from island to island, but generally is about $\frac{1}{2}$ a ϕ-size increase.

TABLE 3. Average Grain Size (Phi-median) of Hawaiian Beach Sands by Season

	WINTER (December-January-February)	SUMMER (June-July-August)
Kauai	0.84ϕ	1.41ϕ
Oahu	0.66	1.22
Molokai	0.56	0.87
Lanai	1.35	1.51
Maui	1.01	1.62
Hawaii	0.61	1.14

Other parameters of sand grains. Grain shape and grain roundness were estimated for each ϕ-size of several dozen samples by comparing microscopically the visual appearance of a sample with standard illustrations. Shape is considered in terms of the relative length of the longest axis of a grain (its maximum diameter), the shortest axis (its minimum diameter) and the axis perpendicular to the first two (intermediate diameter). Four general catagories were established: (1) equant grains, with all three axes nearly equal; (2) prolate or rods, with one axis longer than two others nearly equal; (3) disks or tablets, with one axis shorter than two others nearly equal; and (4) blades, with all axes unequal. Pettijohn (1957) discusses shape analysis and illustrates the limits of each category.

For calcareous sands, about 40% of the grains in a sample were equant and 40% were prolate. Ten percent, or a little more were disks and 10% or less were blades. Although the grains of any composition could be almost any of these shapes, generally, most of the equant grains were foraminifera and fragments of calcareous algae, whereas the bladed and tabular grains were mostly mollusk fragments. Most grains abraded from calcareous algae were prolate to equant.

Increases in the volcanic component of the sand generally resulted in a greater percentage of equant and prolate grains.

Roundness of grains refers to the degree of lack of angular corners and edges. By these definitions, a cube and a sphere are both equant grains, but one is very angular and the other is well rounded. Nearly all grains in most samples were rounded to well rounded, according to standard categories. More angular grains were in the finer grain sizes, broken foraminifera shells, and some of the black sand volcanic glass.

Density determinations were not made because of problems of sorting a sufficient number of grains of one component to obtain a precise measurement from a balance. When unaltered and without voids, aragonite and basalt are of nearly the same density; calcite is less dense and olivine is denser. Grains with considerable void space, such as foraminifera shells, coral fragments, and Halimeda joints, have a lower over-all density than a solid grain of the same size, shape, and mineral composition.

Shape, roundness, and density of grains all affect the hydraulic behavior of the grains. For example, Halimeda joints, which are disk-shaped and very porous, were observed by divers as being sorted into ripple-crests under wave conditions so gentle that no other grains were moving. Yet the Halimeda grains were among the largest grains in the vicinity.

Sand Loss

Beach erosion. Sand on a beach may be lost in any combination of several ways. In response to varying wave conditions sand may move onshore and offshore, as it does at Disappearing Sands Beach near Kailua, Kona, Hawaii, or back and forth along the shore, as it does at Lumahai Beach, Kauai. As a general rule steeper waves provide a more active nearshore circulation, with increased rip currents and a larger amount of sand held in suspension. This situation results in erosion of the beaches.

Because the greatest amount of sand is in suspension a few feet inshore of the breaking point of waves, erosion and transportation will be accelerated or decelerated as breakers move closer ashore or farther offshore as changing wave height and period respond to the nearshore topography.

Both short- and long-term periods of beach erosion occur. Most of the changes due to changes in wave characteristics from storms or particular seasons of the year are reversed when the waves become gentle and sediment is moved onshore. Long-term and often permanent changes have both natural and man-made reasons. There may be a very long, slow change of one of the energy factors. For example, Wentworth (1949) demonstrated that for the period from 1905 to 1937 the approximate azimuth of the tradewinds approaching Honolulu shifted from 044° (roughly northeast) to 089° (roughly east), and from 1937 to 1946, back to 064°. Undoubtedly such changes of wind would cause changes in direction of wave attack and current circulation.

Another type of long-term change is the erosion of black sand beaches on the Puna, Kau, and Kona Coasts of Hawaii. The sand for these beaches was formed, in a brief instant of geologic time, of grains of basalt glass when hot lava chilled and exploded upon flowing into the sea. There is no replenishment of sand, as from a stream mouth or off a reef, unless another eruption were to send a flow to the identical spot. Therefore there must be a long-term and irreversible loss of sand as the sand is removed by storm waves to deep water, or blown inland into dunes.

Some of the changes caused by man are due to removal of more sand from a particular beach than can be replenished, and some are due to interference with the source of sand. An example of the former was last year's (1962) sand removal operations on Papohaku Beach, Molokai. Papohaku is long and has a large volume of sand. The sand drifts to the southwest end, Puu Koai, most of the year, from where it is lost. The sand-dredging operation at the south end of the beach is, therefore, a well-designed one, and sand should be available for decades if it is not removed too fast in any one year. As pointed out in the description of Papohaku Beach, however, the removal of sand last year continued into the winter months, so that when Kona storms came and the alongshore drift was reversed to the north, there was not enough beach left immediately in front of the installations and these were subsequently wrecked by the waves.

Except in a very few instances, such as at Kapukuwahine on southwest Molokai, it has been impossible to determine from valid, objective measurements, the extent to which removal of sand from a beach has been the direct cause of significant beach erosion on nearby beaches. An example that commonly is cited is the supposed erosion since the early 1940's of Sunset, Kawailoa, and Haleiwa beaches from sand exploitation at Waimea Bay. Although operations at Waimea Bay may very well have contributed, the evidence does not allow proof. Sunset Beach is up, rather than down, the prevailing alongshore drift. Changes shown on air photographs since 1949 are within the annual changes measured in this study, even though sand exploitation from Waimea Bay ceased before the study commenced. There have been changes in the tradewind direction, and no severe tsunami on the north coast of Oahu between 1923 and 1946, but three have occurred since then. Unfortunately, there is no long-term record of surveyed beach profiles there, or elsewhere, in Hawaii.

Even though data are not available to prove the degree of man's contribution to problems of local beach erosion, undoubtedly man has been a factor. A suggestion of the order of magnitude of man's contribution to erosion in the Spreckelsville, Maui, area was made by D. C. Cox in 1954 in an unpublished report to the Hawaiian Sugar Planters' Association. Cox estimated a loss of between 16,000 and 27,000 cubic yards of sand per year from these beaches. In addition to direct removal of sand, changes have probably been due to dredging and engineering construction. The site closest to displaying good proof of the harmful effects of man's interference with geologic processes in the nearshore environment is at Kapaa, Kauai, where a hole dredged in the reef is trapping the sediment that normally would have moved across that spot to nourish the beach, now eroding. Kapaa is discussed in the special studies chapter below, and the research there is continuing.

It is very likely that removal of part of the reef off Waikiki has accelerated the seaward circulation there, and has probably increased the erosion. Along several coastlines of the world beaches have not been able to recover from the construction of seawalls, and Waikiki may also be an example of this.

Pollution of reef-dwelling animals, by mill effluent or sewage, w ll have an ultimate effect of destroying the local source of lime sand. Vegetation destroyed inland by overgrazing allows rapid sheet-flood and erosion of mountain slopes, resulting in the spread of pebbles and mud on beaches.

Transport to deep water. Because the orbital velocity of wind-driven waves dimishes so rapidly with depth very little sand-size grains can be moved by the waves in water deeper than a few tens of feet. It also is difficult to transport sand up steep slopes. For these reasons most of the sand that reaches depths beyond 30 feet probably is lost to the nearshore system. This situation is especially true if a steep slope, such as a reef front, must be surmounted. For the same reasons, sand transported to a depression on the reef-flat will tend to be trapped there until the depression fills. Most of the low places on reef-flats have a thin layer of sand.

The lowest places of all on most reefs are channels a few feet to as much as 60 feet deeper than the adjacent reef. These features are most abundant on Oahu, the island with the greatest development of fringing reefs but several have been observed on each of the other large islands excepting Lanai, which may have none. Even where the coral growth is not near the surface, such as some of the so-called reef slopes off leeward Oahu, there may be similar channels. The channels usually are off the mouths of streams and may represent gulches cut through exposed reefs at the time of the last lowering of sea level in the Ice Age. As the waters rose and corals re-established themselves, fresh water in the streams inhibited coral growth there. Later, and continuing today, shifting sand on the channel floors prohibited establishment of corals.

The sandy bottoms of the channels are their most significant feature as far as present day coastal geologic processes are concerned. As pointed out elsewhere in this report, there may be a much greater volume of sand in those channels than in the adjacent beach systems. The rip currents of nearshore circulation patterns flow through the channels, and presumably the water draining off the reef-flat during a large tsunami every several decades would be funneled through the channel. The net movement of sand in the channels, therefore, must be seaward to a point beyond which it cannot be returned by waves.

Fragments of Halimeda, an alga that lives only in water sufficiently shallow for sunlight penetration for growth, were present in sediment samples dredged at several hundred fathoms from one of the submarine canyon floors off the Napali Coast of Kauai during a 1962 Scripps Institution of

Oceanography cruise led by Dr. F. P. Shepard. This is an extreme example of the permanent loss of some shallow-water sediment to deep water. Kuenen (1950) and some other investigators have suggested that sediment is transported down submarine canyons after being mixed in turbid masses of water that flow down slopes because the turbidity current is denser than the surrounding water due to its content of suspended sediment. Other geologists have questioned the effectiveness of turbidity currents and have observed sand cascading down the bottoms of shallow canyons whenever the slopes are steeper than the angle of repose of sand.

Beachrock. Beachrock is a stratified calcareous sandstone or conglomerate common along many tropical lime-sand beaches. Its formation in Hawaii and elsewhere where it has been studied appears to be limited to within the inter-tidal zone. However, older beachrock which formed at different sea levels of the geologic past may be found at elevations higher or lower than present sea level.

As beachrock forms it removes the sand, thus cemented, from the shoreline budget. Unfortunately, the most common position of the beachrock is at that part of the beach most useful for man's recreation--the shoreline he crosses in bare feet to go swimming. An equal volume of sand lost either offshore or as dunes would not be as damaging.

Beachrock may form rapidly. It is common to observe fence wire and posts, coke bottles, and similar recent refuse cemented in beachrock. In parts of coastal India the annual crop of beachrock is harvested for building stone. The Honolulu Academy of Arts building was constructed in part with beachrock quarried from West Molokai.

The cementing material is calcium carbonate, usually as both calcite and aragonite. In the initial stage of cementation thin coatings of cement are deposited around each grain as a result of phys ochemical changes in the interstitial water. An increase in calcium ion concentration, in alkalinity, or in temperature all aid precipitation. In later stages, because the interstitial voids fill, beachrock becomes as durable as concrete.

Several proposals have been made as to the nature of the actual chemical changes. After their investigations of beachrock in the Hawaiian Islands, Emery and Cox (1956) believed that precipitation of calcium carbonate may be either from sea water that seeps through the beach or from fresh to brackish ground water saturated with calcium carbonate from a limestone terrain inland that percolates out toward the sea. Emery later contrasted the relative rareness of beachrock on Guam with its abundance on atolls, and concluded from his analyses of interstitial waters that the brackish water percolating through Guam beaches is undersaturated with calcium carbonate, whereas atolls with little or no ground water have only sea water with its usual tropical supersaturation of calcium carbonate to seep through beach-sand pores (Emery, 1962). Ginsburg (1953), in a study of beachrock in southern Florida, also supported the interstitial seawater hypothesis, but also emphasized differences due to local changes in permeability of beach sand. Some other views have been those of Russell (1962), who concluded from a worldwide study of beachrock that the calcium carbonate which becomes the cement is obtained from ground water rather than from sea water, and those of Kaye (1959), who believed the precipitation was in large part biochemical, from blue-green algae. Kaye's work, as reported in his thorough study of shoreline features in Puerto Rico, has considerable supporting data, but it has received no confirmation from recent investigators elsewhere.

The uncertainties suggest that beachrock may be formed in more ways than one. For Hawaii, at any rate, the proposal of Emery and Cox still appears valid.

Beachrock is very well developed on the westernmost part of Kauai near Nohili and locally elsewhere as at Kekaha and at Koloa Landing. Beachrock is extensive on Oahu; it is found at Nanakuli, Maili, Mokuleia, Kawailoa, and Kahuku. The south coast of West Molokai, the shoreline and offshore north coast of Maui from Kahului to a few miles east of lower Paia, and the south coast of Maui between Maalaea and Kihei all have long stretches of beachrock. Local portions of the beaches of Niihau and Lanai have been cemented into beachrock.

Because beachrock forms at the shoreline, the lines of north Maui beachrock at sea level, although situated from a few feet to a few hundred feet offshore, show the extent of coastal erosion from those former shorelines in relatively recent times. A similar relationship is true at Salt Pond west of Hanapepe Kauai. Beachrock indicates shifts in coastline trends where, although it is present, it does not parallel the present-day beach. Beachrock is resistant to erosion, and on a long beach outcrops of it may be the points holding major cusps of sand.

The sand of a beach fronted by recent beachrock paralleling the present coastal trend may be eroded rapidly behind the beachrock wall by waves of certain characteristics. Small waves do not cross the band of rock and large waves may throw on the beach as much new sand, suspended in the surf zone under large-wave conditions, as they erode. Intermediate waves may overtop the rock, but cannot run back down or seep into a beach foreslope. Water piled up behind the beachrock runs off parallel to the beach until it meets a break in the beachrock. These streams of ponded sea water erode trenches shoreward of the beachrock ridge. Under other wave conditions the trenches usually fill with sand.

Abrasion. Controlled laboratory abrasion tests simulating surf conditions were performed on several natural and artificial local sands. Information obtained to date show that abrasion is of much greater significance in Hawaii than on most other coasts. Calcareous grains and basalt grains abrade at about the same rate, which is more than 1000 times as rapid as that for quartz grains of the same size and roundness.

It is also significant that the rubbing of the grains past one another makes a fine sludge of particles of fine-silt and coarse-clay size, rather than splitting or chipping off fairly large pieces of grains. The fine material can be removed from the beach system even by weak currents.

Local materials vary in their susceptibility to abrasion. Generally speaking, coarse-grained sands abrade faster than fine-grained ones, except in the case of corals. Apparently for coral grains there is a size at less than which the fragile structure shatters entirely. Of detrital grains, weathered basalt abrades very much more rapidly than fresh basalt, and both olivine and basaltic glass abrade somewhat less rapidly. Coarse-grained echinoid (sea urchin) fragments abrade more rapidly than any other fresh coarse grains tested.

Deflation. The effectiveness of the wind in blowing sand off the beaches is easily established wherever dunes are found. Some of the dunes in Hawaii were formed during a time of lowered sea level when large quantities of sand on the reefs were exposed to the wind. Most of these older dunes are now cemented to eolianite. Windward Oahu, West Molokai, Maui Isthmus, and to a less degree southeasternmost Kauai are areas of extensive older dune development. These also are areas of dune formation today, although much of the sand is trapped in vegetation on the dunes and hence the dunes do not appear to be active in areas of high rainfall.

Some additional dune areas are Nohili to Polihua and south of Wailua River on Kauai, Maile, Keawaula (Yokohama) and most of the north coast of Oahu, and Waipio and Pololu Valleys on Hawaii. As pointed out in the sections on atmospheric winds and on geology of coastal segments, most dunes are aligned with the trade winds.

Storm beaches. A minor loss of sand from the nearshore system is the deposition of sand by storm waves well inland of the normal shoreline. If the sand thus deposited falls on bare rock--and there are few plants that flourish in such a saline environment--it is prone to easy removal by the wind.

Some of the exposed points having storm beaches are Kahuku on Oahu and Laau and Kalaupapa on Molokai. The extensive storm beaches of North Kona from Kailua around the west low bulge of Hualalai volcano attest to the severity of the occasional large Kona storms there. These Kona beaches have abundant coral gravel.

Man. In several localities man has been an important agent in the removal of sand from the nearshore and beach systems. Some loss has been directly from exploitation of beach sand for construction purposes and some indirectly from changes in the shapes of harbors and other works that have caused changes in the nearshore circulation or the source of materials. Because sand is so necessary for concrete, and because river sand is so rare in Hawaii, coastal sand will undoubtedly continue to be used in the State. Probably sand will also be used to nourish eroding beaches that have a high user-density.

Of the three places from which sand may be taken--offshore, the beach, and dunes--probably the last named is the best from a conservation point of view, as it is unlikely that dune sand would enter the nearshore circulation again.

For sand-dreding operations it would seem that the best locations are down the alongshore drift near points of land or at the heads of channels that are natural avenues of loss. Locations elsewhere should be discouraged.

Offshore sources of sand, which may be economically unsuitable, however, include large sand flats, as in Kaneohe Bay, as well as the sand which has drifted into the channels across the reefs or into deep water beyond points of land. Such sand is otherwise lost to the beach systems.

Natural Disasters in Shoreline Areas

Introduction. This section is a summary of the past history and probability of future occurrences of tsunamis, landslides, earthquakes, and similar natural disasters of shoreline areas in Hawaii. Beach erosion, one of these natural processes, has been discussed in the preceding sections. Where possible, recommendations for avoidance or protection are listed.

Most of the information contained in this section was obtained from the reports of the Tsunami Research Program of the Hawaii Institute of Geophysics and from the geologic bulletins of the Hawaii Division of Hydrography on the individual islands. Geologic terms are as defined in Leet and Judson (1958). In general, specific references are not made to these publications. For the reader desiring an account that is more complete than this summary, the annotated bibliography of this report should be consulted. The first chapter, on Tsunamis, was prepared by Mr. D. C. Cox, geophysicist in charge of the Tsunami Research Program. Some good general sources of tsunami information, in addition to those referred to by Mr. Cox, are: Cox (1961, 1963), Mink and Cox (1963), Eaton, Richter, and Ault (1961), Fraser, Eaton, and Wentworth (1959), Macdonald and Wentworth (1954), and Shepard, Macdonald, and Cox (1950).

Sources consulted for other chapters of this section are as follows: Storms: Groen and Groves (in Hill, 1962); Saul Price (personal communication). Geology of individual islands: Oahu: Stearns and Vaksvik (1935), Stearns (1939, 1940b); Lanai and Kahoolawe: Stearns (1940a); Maui: Stearns and Macdonald (1942); Hawaii: Stearns and Macdonald (1946); Molokai: Stearns and Macdonald (1947); Niihau: Stearns (1947) and Macdonald (1947b); Kauai: Macdonald, Davis, and Cox (1960); various islands: G. A. Macdonald and D. C. Cox (personal communication).

Tsunamis: by D. C. Cox

Definition. Tsunamis are trains of long waves having periods from several minutes to about an hour, impulsively generated in the ocean (Cox, 1963). Together with storm surges, which are long waves generated by atmospheric disturbances, tsunamis are commonly known as tidal waves, although they resemble the true tides only in manifesting at some places gentle rises and falls of water level. Because they are usually associated with earthquakes, tsunamis have also been called seismic sea waves.

General Characteristics and Behavior. Tsunamis originate most commonly in the seismically active belt surrounding the Pacific Ocean. Iida (in preparation) has found records of more than 350 tsunamis in the Pacific, of these about 120 were generated near Japan, about 50 off the shore of South America, and about 30 off the shores of the Kuril Islands, Kamchatka, and the Aleutian Islands.

The association of tsunamis with earthquakes suggests that they are generated by the sudden fault displacements of the ocean floor that cause the earthquakes. However, tsunamis may also be generated by submarine land slides that may be triggered by the earthquakes, of by sub-aerial landslides slipping into the water, or even by volcanic explosions or collapses. Essentially the same kind of wave trains may be generated by sufficiently large artificial submarine or surface explosions, such as nuclear explosions. All of these modes of generation are sudden, or impulsive, as contrasted with the continuing atmospheric pressure disturbances that generate storm surges.

It is important to recognize that tsunamis are not single waves but trains of successive waves. The largest wave is frequently not the first, but commonly is the third or some later wave in the train. The term "long waves", as used in the definition of tsunamis, indicates that the wave lengths, i.e., the distances between successive waves in the train are much greater than the depths of the ocean, even at its greatest depth.

The waves in the important front sections of tsunami wave trains have wave lengths of at least 30 or 40 miles and sometimes, perhaps 300 or 400 miles. In contrast, the ocean is in general only about 3 miles deep, and in its deepest trenches, only about 7 miles deep.

Because their wave lengths are so great in comparison with the ocean dpeth, tsunami waves behave as "shallow-water" waves whose velocity is proportional to the square root of the depth. In mid-ocean (15,000 to 18,000 feet depth) a tsunami travels with a velocity of about 450 to 500 miles per hour. However, as the water shoals near land, the tsunami velocity decreases so sharply that in water of 1000 feet depth it is traveling at only about 120 mph, and in water of 60 feet depth, at only about 30 mph. Along with the decrease in velocity, and the concurrent decrease in wave length, there is an increase in height. The waves of even a large tsunami may be only about a foot high in mid-ocean. In water of 1000-foot depth, however, the height would approximately double, and it would double again where the water decreases to a 60-foot depth.

As the waves of a tsunami spread out from the point of origin, they do not remain regular, but develop salients and re-entrants where they have moved, respectively, over deeper and shallower water. Concommitantly, the energy in the waves diverges and converges in a complicated way leading to variations in wave height along the same wave. As the waves move near shore this behavior becomes increasingly complex, and other processes induce differences in energy and height from place to place. For example, large abrupt discontinuities in depth lead to partial reflection of energy back to sea. The waves may set into oscillation the waters of harbors and bays whose natural periods match those of the tsunami. The sides of bays may guide the waves in such a way as to cause increases in height. The waves may increase so greatly in height and steepness that they break and form bores similar to those caused by extreme tides.

The widths of coasts which the waves finally inundate and the heights to which they finally attain are controlled complexly by their heights and velocities as they cross the shoreline, and by the steepness and roughness of the coast. The runup heights attained in the same tsunami, one which may have been only about a foot high in mid-ocean, may range from only a foot or two along one part of a shoreline to 20 or 30 feet along others. At some places the water may rise and fall gently with the arrival of successive crests and troughs of a tsunami, while at other places the same waves may rush onshore with great violence. Even when the waves are high, the damage at the first places may be limited to remarkably gentle floating of frame buildings off their foundations plus the effects of wetting, while at the other places buildings may be smashed, huge rocks rolled around, and so forth.

Tsunamis in Hawaii. Because of their position in the middle of the Pacific Ocean, the Hawaiian Islands are affected by tsunamis from most of the circumferential belt of tsunami generation. Since 1819, when the historic record of tsunamis in the islands begins, some 50 tsunamis have been recorded from sources as shown in Tables 4 and 5.

Warning System. From 1923 at least through 1938, informal warnings of tsunamis were issued in Hilo by the Hawaiian Volcano Observatory based on indications from observatory seismographs of the occurrence of large earthquakes in the Pacific.

The present warning system operated by the Honolulu Observatory of the

TABLE 4. Source Areas of Tsunamis in Hawaii

Source Area	Total Number of Tsunamis	Number of Important Tsunamis
Kermadec, Tonga, Fiji, Samoa Islands	4	
Solomon Islands, New Guinea	3	
Philippines	1	
Japan	6	1
Kuril Islands, Kamchatka	9	4
Aleutian Islands, Alaska	4	2
California, Mexico	6	
Columbia, Peru, Chile	12	7
Hawaii	3	1
Unknown	2	
	50	15

Dates, sources, and characteristics of 18 of the most important of these tsunamis are shown in Table 5.

U. S. Coast and Geodetic Survey (Zerbe, 1953) utilizes both seismographic and marigraphic information. Seismograph stations and tide-gage stations scattered around the Pacific supply information through a complex communication system. Advisory messages are released when large earthquakes have occurred in the Pacific, but warnings are issued only when the generation of a tsunami has been confirmed or when advance reporting cannot be expected.

The warnings are issued to the Civil Defense Agency and police departments. They are transmitted to all populated coastal areas and disseminated by siren signals, radio broadcasts, police mobile loudspeakers, and wardens. Shoreline areas are supposed to be evacuated when tsunami warnings are issued.

Potential inundation areas. Areas of potential inundation by tsunamis were outlined in 1961 as a guide to appropriate evacuation during tsunami warnings (Cox, 1961). In the designation of the potential inundation areas it was assumed that tsunamis in the future would not be larger than those recorded in the past. However, it was considered that place-to-place differences in the extent of inundation and height of runup of the historical tsunamis could not safely be used in detail in the prediction of future effects because of expectable variation in the character and direction of approach of the waves. On study of past records, only two causes of variation were found to be useful. The first is the slope of the ground, and the second, the exposure relative to the direction from which tsunamis have historically come.

The following ass mptions were found to provide a generally satisfactory margin of safety beyond historical maximum inundation limits:

TABLE 5. Important Tsunamis in Hawaii

Date	Source	Remarks	Max. heights, ft. Hilo	Kahului	Honolulu
1819 Apr 11	Chile	Observed in Honolulu.	?	?	5
1835 Feb 20	Chile	Damage reported on Kauai.	?	?	?
1837 Nov 7	Chile	Violent attack in Hilo, 14 killed, more than 66 houses destroyed. Damage in Kahului, 2 killed. Ships grounded in Honolulu Harbor.	20	?	4
1841 May 17	Kamchatka	Gentle rise and fall in Hilo.	15	?	1
1868 Apr 2	Hawaii Is.	Earthquake epicenter off S. Puna and Kau; runup height reported to 60 ft. there, 81 killed. Some damage in Hilo. Observed on Maui and Oahu.	10	?	2
1868 Aug 13	Peru-Chile	Some damage in Hilo.	12	6	2
1877 May 10	Chile	Serious in Hilo, 5 killed, 37 houses destroyed.	16	8	2
1878 Jan 20	unknown	Some damage north coast of Maui, Oahu.	?	?	?
1896 June 15	Japan	No damage in Hilo.	8	?	+
1906 Aug 16	Chile	Damage at Maalaea, Maui. Ships grounded,Kapaa, Kauai. Damage at Kailua, Kona.	2	?	+
1918 Sept 7	Kuril Is.	Minor damage in Hilo.	5	?	?
1922 Nov 11	Chile	Some damage in Hilo.	6	?	1
1923 Feb 3	Kamchatka	$60,000 damage in Hilo, 1 killed. $500,000 damage in Kahului.	20	12	1
1933 Mar 3	Japan	Minor damage Kailua, Kona.	2	?	1
1946 Apr 1	Aleutian Is.	Disastrous in Hilo, 68 killed, 250 buildings destroyed, breakwater heavily damaged, $27 million damage. Heavy damage north coasts of Maui, Oahu, and Kauai. 159 killed in total	26*	22	9
1952 Nov 4	Kamchatka	6 buildings destroyed in Hilo, $285,000 damage. Some damage Waialua, Oahu, and Kahului, Maui.	11*	?	2
1957 Mar 9	Aleutian Is.	$416,000 damage in Hilo. Heavy damage Waialua, Oahu. $1,500,000 damage north coast Kauai.	13*	13	6
1960 May 23	Chile	Disastrous in Hilo, 61 killed, 537 buildings destroyed, $22 million damage. Heavy damage Kailua, Kona, and Kahului, Maui.	27*	12	9

? No record of height located.
\+ Waves recorded; height small, generally less than 1 foot.
* Normal maximum height; highest values somewhat higher.

1. It was assumed that the waves of a tsunami might rise on any coastline 50 feet high above mean sea level against a cliff arising out of deep water, but that their runup height would decrease one percent with distance traversed over water shallower than 10 feet or over land, and half of a percent with any distance in excess of 1,000 feet traversed over water between 10 and 20 feet depth. It was assumed that the diminution in height would begin at the entrances to channels less than 2.000 feet wide (or 2,600 feet in the case of Kaneohe Bay, Oahu), rather than where the water finally shoaled to 10 feet inside bays, estuaries, harbors, or canals. It was assumed that the water could rise as much as 4 feet above mean sea level anywhere within 400 feet of the shore of the ocean or tidal bodies.

2. Except with tsunamis from the southwest, much larger than those historically recorded, the sheltering effect of the islands, it was assumed, would reduce the potential rise against a cliff to 30 feet on southwest coasts. The channel effect would be the same as with the 50-foot potential rise.

3. At nine places the limits of potential inundation drawn in accordance with the above assumptions provided an insufficient margin of safety. Eight of these places, all on northeast coasts, were Wainiha and Nawiliwili on Kauai; Waialua on Oahu; Kahului, Spreckelsville, and Maliko on Maui; and Hakalau and Hilo on Hawaii; and one, on a southwest coast, Iroquois Point on Oahu. For these places lines were drawn on the basis of the historical records.

4. The limits of potential tsunami inundation zones for inhabited shorelines of Kauai, Oahu Maui, and Hawaii, defined as discussed above, have been plotted on flood control maps of the State Division of Water

and Land Development (1963), and also on shoreline planning maps of the State Department of Planning and Economic Development. Where the limits of potential inundation have not been determined, they may be assume to lie no higher than 50 feet above sea level.

Protection. Through the tsunami warning system, which is intended primarily to save lives, a certain amount of readily movable property can be saved when a tsunami threatens. To reduce losses of permanent improvements, however, other measures are required. Structures may be erected to reflect or deflect the waves; rough terrain, vegetation, or structures may be provided to reduce the inundation; buildings in the potential inundation zone may be designed to minimize damage in case of flooding; the potential inundation zone may be kept clear of improvements; or there may be combinations of these measures.

Because of the size, strength, and cost of structures adequate to reflect or deflect the waves of a large tsunami, the practicality of such structures is limited to places where the value of the improvements to be protected is high and the risk of inundation is great. Both sea walls and breakwaters have been considered for the purposes of tsunami protection. Sea walls have the disadvantage of incompatibility with many of the uses of shoreline areas. The effectiveness of breakwaters against waves having periods as long as those of tsunamis is uncertain. The design of tsunami protective structures is far from being reduced to standard engineering practice, and each problem involves extensive research. A major construction project for tsunami protection has been proposed for the city of Hilo (Corps of Engineers, 1961). The research phase of this project has already involved intensive mathematical analysis and hydro-dynamic laboratory work and is now continuing with large scale hydraulic model experimentation (Takahasi, 1962).

Any roughness in the surface being inundated by a tsunami tends to reduce the extent of inundation. Natural groves of trees have been observed to have a significant effect of this sort. Groves have been planted in Japan, especially as tsunami protection, and a similar pract ce has been recommended in Hawaii.

Within the zone of potential inundation, buildings may be constructed to withstand the force of the waves or to allow them to pass without having maximum effect. A few reinforced concrete structures of suitable design have withstood the effects of both the 1946 and the 1960 tsunamis in Hilo, and some houses have now been built in which the essential parts, at least, are elevated sufficiently to allow most tsunamis to pass beneath them.

The simplest solution to the problem of protection of improvements against tsunamis consists of not constructing improvements in the potential inundation zone. This solution is, in general, quite compatible with the dedication of shoreline areas to recreational use. The Kaikoo Redevelopment plan for Hilo includes such dedication for most of the area that was disastrously affected by the 1960 tsunami.

In general, economics are best served by some combination of protective measures.

Research. To promote improvements with tsunami warning systems, in the definition of potential inundation areas, and in the design of protective measures, fundamental research on tsunamis is in progress in many parts of the world, but especially in the United States, Japan, and the USSR.

Work on the seismic accompaniment of tsunamis, on certain phases of tsunami hydrodynamics, on recording instrumentation, and on the history and frequency of tsunamis is in progress in Hawaii (Cox, 1963; Cox et al, 1963).

Storms. Inundation of coastal areas might also be caused by abnormal meteorological circumstances. Storm surges are sea-level disturbances, with periods from a few hours to a few days, of nearby atmospheric origin. When combined with spring tides, surges have been the most catastrophic natural disasters of many continental coasts, for example the Atlantic and Gulf coasts of North America, India, and the North Sea. Past history suggests Hawaii has little to fear from flooding by a rising sea during a storm surge, and in fact the amplitude of surges is seldom large at islands rising sharply from the deep ocean (Groen and Groves, in Hill, 1962, p. 620).

Winter swells originating near the Aleutian Islands, that commonly cause severe damage to property on north coasts along the Hawaiian chain, are not true storm surges. Their effects have been described in the section on waves.

Besides increasing the activity of the sea and initiating marine flooding, as mentioned above, storms may lead to damage from wind and stream flooding or may start landslides. Because these disasters may be in coastal areas, they are discussed briefly in this report. Most of the damaging windstorms and rainstorms in Hawaii are merely local intensifications, due to local topographic configurations, of some of the heavier general kona storms. Storm run-off leads to flooding by streams both inland and along the shore. Flood plains commonly widen in low coastal areas, and sedimentation from flood-waters helps build the shoreline seaward along the accretion coasts of Kaneohe Bay, Oahu, South Molokai, and North Lanai.

One troublesome feature, indirectly related to shoreline processes, is stream flooding by waters ponded behind a beach which has been built by wave action into a bar across the stream mouth. Waimea, Kailua, and Maili on Oahu have frequently suffered from this type of flooding. Preventive measures would be to bulldoze aside some of the sand periodically during periods of no stream flow as suggested by C. K. Wentworth and D. C. Cox in 1951, in an unpublished report to the Conservation Council of Hawaii, or to provide coastal swamp areas with better drainage canals or channels and permanent exits in the bedrock to the side of the beach, which should remain unblocked by sand.

In addition to these general storms, Hawaii has also suffered from rare storms of types that generally are very destructive. Two tornadoes on land and several waterspouts at sea have been recorded. Prior to 1950 no Hawaiian storms were definitely identified as hurricanes, yet since that year four small ones have passed through the islands. These have been decidedly smaller in size and strength of the wind than the better-known Caribbean hurricanes and West Pacific typhoons. Damage is of the same order of magnitude as the local intensifications of kona storms mentioned in the preceding paragraph. Were we to be visited by a full-scale hurricane, there would be not only a greater likelihood of direct windstorm and rain run-off damage, but also, of flooding from storm surges induced by the wind-stress and air-pressure changes.

Mass-wasting. The danger to shoreline areas from mass-wasting, the en masse downslope movement under gravity of rock debris, is relatively insignificant except in areas of very steep slopes. The slow movements of soil creep, solifluction, and rock glaciers are either unimportant in Hawaii or non-existant under our present climatic regime. The rapid movements, or various types of landslides, include the more destructive kinds of mass-wasting in Hawaii.

Slump, or slope failure of large masses of material downward and outward along curved fault planes, is one of the most common types of coastal landslides elsewhere in the world. Slumps at Santa Monica Bay, California, and on the south coast of England, are among these. Fortunately, in Hawaii, high sea cliffs of poorly consolidated sediments are uncommon, and so are also the slope failures that result from erosion at the base of slopes. During the January-February 1963 kona storms there were slumps of the 10- to 20-foot-high cliffs of old dune-sand at Keawakapu and Kaanapali, Maui, accelerating erosion of the coast there. Because there does not appear to be an inexpensive or easy way to stabilize slopes susceptible to slump, it is recommended that construction and property-improvement be held to a minimum at locations where weak bedrock or poorly consolidated sediments occur along the coast.

Rock slides and rock falls are the most catastrophic of all mass movements. They are sudden, rapid slides or vertical descents of rock masses, ranging from single pebbles to millions of cubic yards, as in the disasters of Goldan (Switzerland, 1806, 475 deaths) and at Frank (Alberta, 1903, 70 deaths). Rock slides down Hawaii's palis are fairly numerous, as attested by the talus slopes along the pali bases. At the foot of the higher sea cliffs, such as the Napali coast of Kauai, Molokai's north coast, most of the north coast of Maui, and the Hamakua coast of Hawaii, there is a constant rain of large and small fragments of the weathering rock.

Some local slides are quite large. During the earthquake of 2 April 1868, a rock-slide from a sea cliff one mile northwest of Waimanu Canyon near Waipio on Hawaii formed Laupahoehoe (not the better known Laupahoehoe several miles to the southeast), a mass of rock waste that was a mile wide at the shoreline and projected one-half mile into the ocean. The steep valley walls and sea cliffs on this eastern edge of Kohala mountain are especially subject to rock slides because of thin, structurally weak, ash beds interlayered with the bedrock lava flows. Stearns and Macdonald (1946) report slides in 1929, 1941, and 1942, and earlier ones of unknown age.

Along the base of the sea cliff north of East Molokai there are several broad peninsulas of rock waste that are evidences of similar immense rockfalls in the recent past. The five largest total more than three miles of coastline. Because protection against large rockfalls is impossible, it is wisest to avoid construction or habitation near the base of steep cliffs, especially in areas of talus that give evidence of a past history of falling rock.

Soil avalanche is a local name (Wentworth, 1943) for a type of debris slide, a relatively small, rapid downward movement of mainly unconsolidated material. Debris slides grade into earthflows, which are slower (yet still show perceptible movement), and in which much of the material deforms plastically. These types of mass movements are especially common on steep slopes with thick soil and vegetation cover during heavy rains. Most of these mass movements in Hawaii, therefore, take place on valley walls where rainfall is high, which generally is toward the interior of the islands. Wentworth estimated that about 25 such slides, averaging an acre in area, occur each year in the 15 square miles of the upper Koolau Range near Honolulu.

Due to generally lower rainfall, debris slides in coastal areas are smaller and rarer, but they may be troublesome locally where a soil-mantled slope is naturally or artificially oversteeped. One such example was the earthflow that buckled the pavement of Kalanianaole Highway near Kawainui Swamp, Oahu, and the associated series of debris slides there, during the winter rains of 1963. The highway cuts were at too steep a slope for the strength of the weathered rock and soil.

Often it is possible to stabilize slides and flows of this type by avoiding the build-up of high pressures of pore-water within the unstable mass. Water does not act as a lubricant, i.e., to reduce friction on the sole of the slide, and only slightly acts as an added weight. Its important role in initiating and sustaining slides of this type is in breaking apart grain-to-grain contacts resulting in reduction of internal adhesion of one part of the mass to another. Some engineering methods used for stabilizing slides of this type have been drilling horizontal "wells" to tap pore water, or covering surfaces with asphalt to keep water out. Probably safer, however, would be the practice of avoiding construction in areas of previous slides, recognizable by the scars of exposed soil and rock which are left after the vegetation and upper part of the soil slips away. Usually a few years are necessary before the vegetation grows back sufficiently to mask the scar. Of course, it is very foolish to excavate artificial cuts at angles steeper than nearby natural existing slopes in areas of heavy soil cover and heavy rainfall.

Mudflows are well mixed slurries of rock, soil, and water that flow down valley slopes with the consistency of freshly mixed concrete. A prehistoric mudflow 10 to 24 feet thick lies in Palolo Valley, Honolulu. The most destructive landslide in historic time in Hawaii was triggered by the earthquake of 2 April 1868; it buried 31 people and more than 500 head of livestock. This flow at Wood Valley near Pahala, Hawaii, was caused by a mass of water-soaked and friable ash, known as the Pahala ash, that is exposed over 450 square miles on Hawaii Island. Fortunately, Pahala ash is rarely very thick in shoreline areas, but it is rather continuously exposed along the northeast coast of Mauna Kea from Waipio to Hilo, and at scattered Kau District coastal localities on the south flanks of Kilauea and Mauna Loa from Keauhou to Ka Lae. Although the Wood Valley mudflow apparent resulted from a combination of (1) one of the thickest sections of ash, (2) abnormally rain-soaked terrain, and (3) a severe earthquake, one might expect minor slumps, or if sufficiently wet, mudflows, throughout the area of Pahala ash exposure.

A mudflow, such as the ones which occurred on Maui during the Pleistocene or Ice Age, were it to be repeated, would have severe consequences in coastal areas. The flow transported several million cubic yards of mud and rock debris from Haleakala down Kaupo Gap and into the ocean. The Pleistocene Paikea breccias of central Kauai are of greater volume, but they did not reach the ocean. Under present volcanic and climatic conditions of Maui, Kauai, or elsewhere in Hawaii, the mudflows of similar magnitude are regarded as next to impossible.

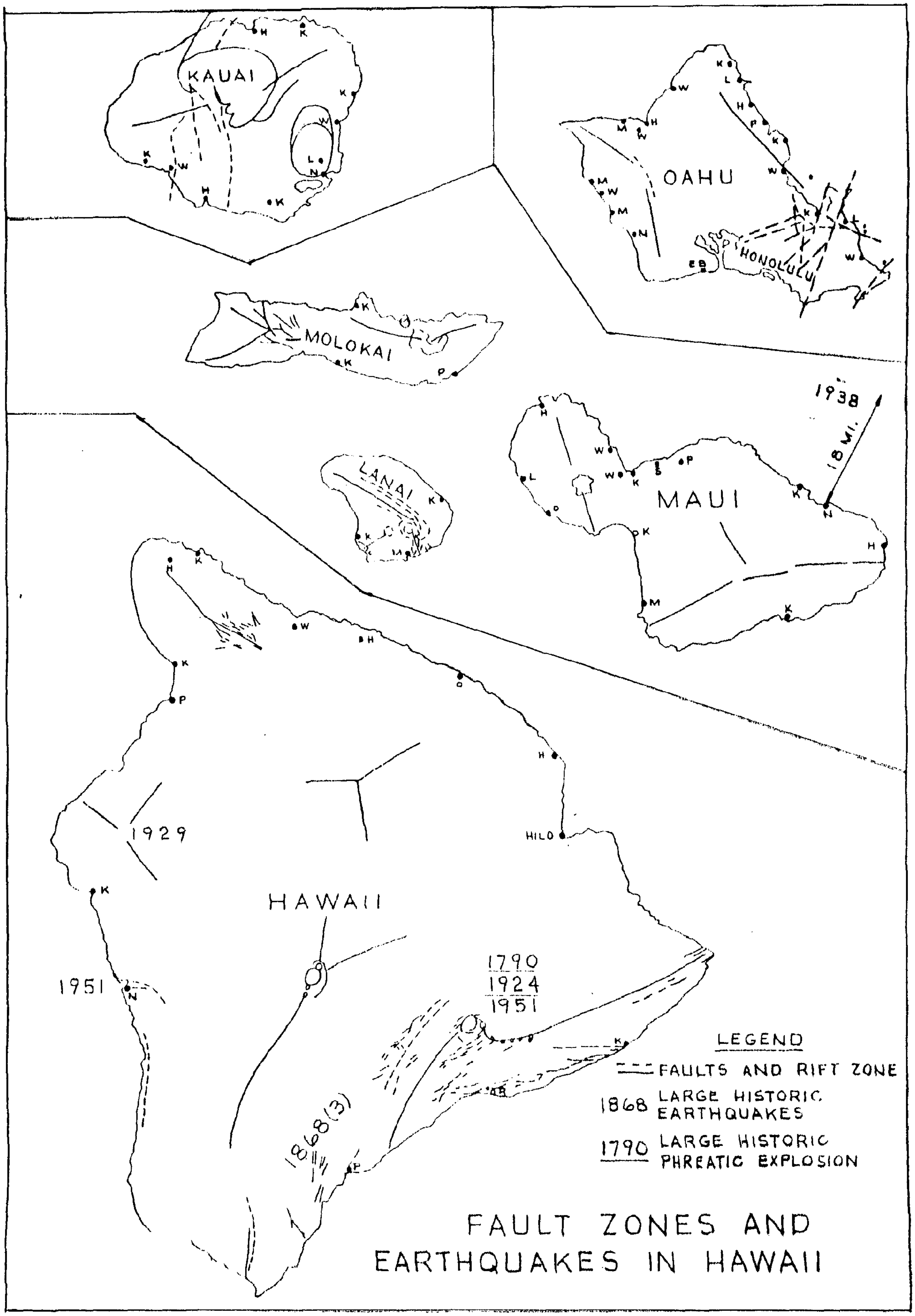
It also is fortunate that the type of volcanic mudflows known as lahars, which are so destructive in Indonesia and other areas of explosive andesite volcanism, would also be unlikely in Hawaii.

Earthquakes and Faulting. Seismologists generally believe that earthquakes are the shocks that result from the breaking of rocks which have been distorted beyond their strength. The Hawaiian Islands have fewer earthquakes than the coasts rimming the Pacific, but more than most areas in ocean basins or in the interior of continents. Some weak but frequent earthquakes at 60 km below Kilauea caldera probably indicate lava generation there in the upper mantle of the earth. Commonly, swarms of weak earthquakes 2 to 3 km below the calderas suggest fractures of the magma-chamber walls during storage there of lavas preceding an eruption. These types of earthquakes cause insignificant damage.

Damage from Hawaiian earthquakes comes from quakes related either to faulting or to steam explosions. Many of the faults (fractures along which the blocks of ruptured rock have moved relative to one another) in the State of Hawaii occur at the calderas or along the rift zones, or paallel the topographic contours of active and extinct volcanoes. Steam explosions occur as water comes in contact with hot rock or molten lava.

Earthquakes are rare on Kauai. Most of the large faults there bound calderas in the interior, but some are at or near the coast south of Nawiliwili, or between Hanapepe and Waimea, or near the center of the Napali Coast (Fig. 93). There are no indications that any of Kauai's faults have been active in the recent past, and no serious earthquakes are expected.

On Oahu the known and probable faults are either in the caldera areas of the Waianae and Koolau volcanoes, or in a later system in the southeastern part of the island. The Koolau caldera is in a shoreline area from Lanikai to Kaneohe Bay, but the chance of reactivation of its faults



KAUAI
OAHU
HONOLULU
MOLOKAI
LANAI
MAUI
1938
18 MI.
HAWAII
HILO
1929
1951
1790
1924
1951
1868(3)
LEGEND
FAULTS AND RIFT ZONE
1868 LARGE HISTORIC EARTHQUAKES
1790 LARGE HISTORIC PHREATIC EXPLOSION
FAULT ZONES AND EARTHQUAKES IN HAWAII

Fig. 93.

is remote. However, the small earthquakes on southeastern Oahu or offshore from it are generally assigned to movements along the fractures through which the late-stage eruptions of the Honolulu volcanic series are presumed to have occurred. The fractures generally trend northeast. One such trend is the Koko Head-Koko Crater-Manana Island alignment of about 9 separate eruptions. Another trend includes Diamond Head tuff cone, Kaimuki lava dome, Mauumae cinder cone, Kaau pit crater, and the Maunawili and Training School flows, and there are additional ones that include such well-known features as Tantalus, Punchbowl, Salt Lake, Moku Manu, and many more. It can be concluded, therefore, that Oahu east of Pearl Harbor, most of which is coastal and urban, is moderately susceptible to small earthquakes, which thus far have caused insignificant damage. Unless there should be a renewal of volcanic activity along these fractures, earthquakes in and near Honolulu should remain of minor consequence.

On Molokai faults bound the East Molokai caldera complexes, and are exposed at the shore at Haupu Bay. A series of faults on the northeast edge of West Molokai approach the shore near Moomomi. All Molokai faults are ancient, and as a consequence no earthquakes are likely to occur.

On Lanai the main faults are in the caldera area of the interior. Some along old rift zones are exposed in sea cliffs on the southwest point of the island, and for about 3 miles northeastward from Manele Bay. No earthquakes are to be expected from these old faults on Lanai.

On Maui there are faults at the West Maui caldera, as well as along the south edge of Haleakala's summit depression and the Southwest and East Rift Zones of Haleakala. Because Haleakala volcano is probably dormant rather than extinct, there is a chance for additional earthquakes on East Maui. The 1938 earthquake was north of East Maui.

Most of the historic Hawaiian earthquakes, of all intensities, have been on Hawaii Island, associated with the active volcanoes. There are numerous faults on Mauna Loa and Kilauea, in the eroded summit area of Kohala, and probably also on Mauna Kea and Hualalai where young lavas cover the caldera area.

In addition to the caldera faults of Mauna Loa and Kilauea, rift zones extend generally eastward and southwestward. Other faults, generally parallel to the coast, extend through most coastal areas from Kaimu in Puna clockwise to Napoopoo in Kona. The various palis south from Kilauea caldera to the ocean, Kahuku Pali near Ka Lae, and Pali Kaholo from Milolii to Hookena, are along these faults. Earthquakes affecting coastal areas can arise from any of these.

The earthquake of 2 April 1868, with a center near Waiohinu, Kau District, deserves a special note. It has been mentioned above that the landslides near Pahala and 70 miles north near Waipio were triggered by that quake. The quake also initiated a tsunami with waves 40 to 50 feet high that swept away all coastal villages for more than 30 miles of coast from Keauhou to Kaalualu. Parts of the Kau Coast were elevated a few feet, whereas the Puna coast was submerged 8 feet near Kaimu and 3 to 6 feet closer to Cape Kumukahi. Displacement on the fault itself was 12 feet.

Earthquakes somewhat less severe also occurred near Waiohinu on 28 March and 3 April 1868. Other large historic earthquakes were one in 1929 at Hualalai, one in 1938 about 18 miles north of East Maui, and two in 1951, one at Kilauea caldera and one at Kealakekua Bay in central Kona. The Kilauea earthquakes of 1790 and 1924 were from steam explosions when molten lava receded and groundwater entered the throat of Halemaumau and contacted the hot rocks. These phreatic explosions are severe near their point of origin, but because of their shallowness they cause only weak earthquakes at moderate distances.

Explosions during eruptions also cause local earthquakes. Basalt, the commonest type of lava in Hawaii, is relatively non-explosive during eruption. Presumably this nature of basalt characteristic is due to its low viscosity and gas content.

Volcanic Eruptions. Earthquakes associated with eruptions were mentioned in the preceding section. Another natural hazard to shoreline areas is the flowing lava of the eruption itself. Mauna Loa and Kilauea have erupted several times and Haleakala and Hualalai have erupted briefly in historic times (Fig. 94). Any part of the Maui Coast from Spreckelsville clockwise via Hana to Kihei and any part of the Hawaii Coast from Hilo clockwise via Ka Lae to Puako Bay might be affected, but the position of rift zones, the type of topography, and the frequency of recorded volcanism mark some coastal segments as more vulnerable than others.

On Maui coasts, the chances of renewed volcanism are exceedingly slim from Spreckelsville to Keanae. From Keanae around to two miles south of Keawakapu about 85% of the coastline is formed by the Hana volcanic series of Pleistocene and Recent age, but only about 5% of the coast (near La Perouse Bay) is made of lava erupted in historic times. Although volcanism from Haleakala probably will continue at infrequent intervals in the next several thousand years, the probability of an eruption in any particular century is low. Shores near the rift zones, near La Perouse Bay and near Hana, are somewhat more susceptible than the rest.

On Hawaii all the coast from Hilo clockwise to Puako Bay is formed of volcanic rocks of Pleistocene and Recent age from Mauna Loa, Kilauea, and Hualalai volcanoes. From the evidence of historic flows, however, five areas are especially prone to eruptions.

Hilo is the coastal populated area having the greatest potential danger. Although no historic flow actually has crossed the shoreline in Hilo, the natural funneling between the slopes of Mauna Kea and Mauna Loa has directed towards Hilo the Mauna Loa flank eruptions of 1852, 1855, 1880 (entered Hilo outskirts in 1881), 1899, 1935, and 1942. Without doubt flows in the future will be directed the same way. Bombing attempts in 1935 and 1942 to divert the flows or to release gas and clot the lavas had indifferent success. There have been proposals for crude, bulldozed en echelon ditches and walls above Hilo to divert future flows (Macdonald, 1962; Wentworth et al, 1961).

Eastern Puna is a second coastal area with a high incidence of volcanism in historic times. About one-third of the coast from Waiakahiula to Kaimu has been covered since 1750 by lava from the east rift zone of Kilauea. The eruptions of 1955 and 1960 were especially troublesome in and around Kapoho. Not all effects have been harmful; littoral explosions have formed some black sand beaches, ash from eruptions has fertilized fields, and several hundred acres of land have been added. Attempts to develop steam wells for geothermal power in Puna have been unsuccessful.

The Kau coast northeast of Punaluu is susceptible to flows from the southwest rift of Kilauea, but there are few inhabitants of that coast. Of somewhat more importance is a fourth section, the coast from Ka Lae to Lae Paakai, in which a half-dozen historic flows from the southwest rift

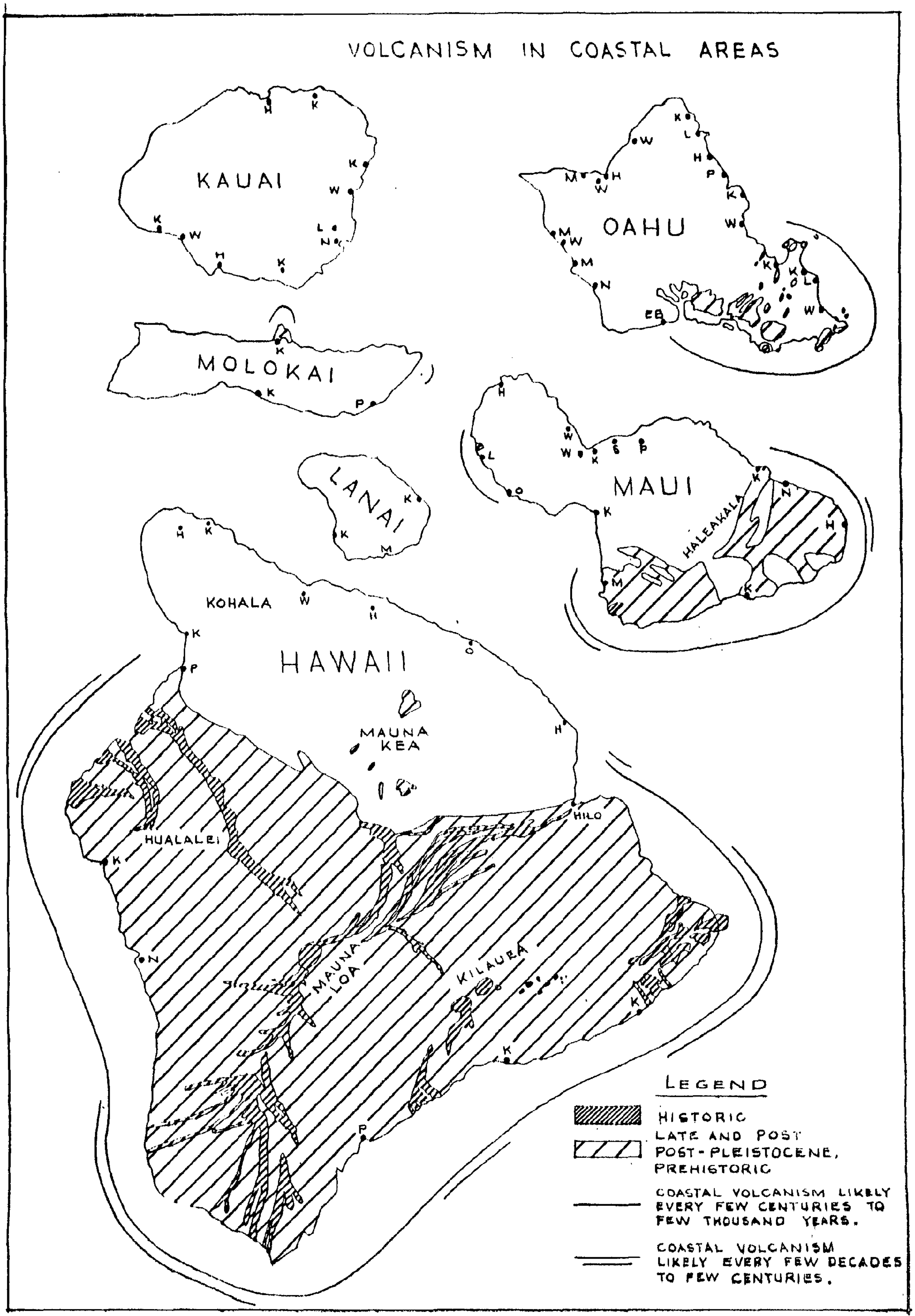

VOLCANISM IN COASTAL AREAS
KAUAI
OAHU
MOLOKAI
LANAI
MAUI
HALEAKALA
KOHALA
HAWAII
MAUNA KEA
HILO
HUALALEI
MAUNA LOA
KILAUEA
LEGEND
HISTORIC
LATE AND POST POST-PLEISTOCENE, PREHISTORIC
COASTAL VOLCANISM LIKELY EVERY FEW CENTURIES TO FEW THOUSAND YEARS.
COASTAL VOLCANISM LIKELY EVERY FEW DECADES TO FEW CENTURIES.

Fig. 94.

zone of Mauna Loa have approached or crossed the shoreline. The 1926 flow buried the village of Hoopuloa.

The last coastal area with a high incidence of volcanism is in North Kona from Keahole Point to Keawaiki Bay, with about one-half the coast made of historic flows from Hualalai and Mauna Loa. Kailua, Kona, lies in a slight swale on the south flank of Hualalai.

Although not nearly as likely to occur as the shield-building flows of the major volcanoes mentioned above (Haleakala, Hualalai, Mauna Loa, and Kilauea), it is within the realm of possibility that a secondary eruption on one of the other volcanoes might occur. The most recent volcanism on Kauai, the Koloa series, is several thousand years old, perhaps before the end of the Pleistocene, even though the lavas have a very fresh appearance in some places. On Oahu there have been about 40 distinct vents of the Honolulu series (Diamond Head, Tantalus, Salt Lake, etc.) active since the middle of the Pleistocene. There is no reason today to modify the conclusions of Stearns, who wrote (Stearns and Vaksvik, 1935, p. 165) "There is ample evidence that these eruptions occurred spasmodically every few thousand years up to Recent time. Consequently, there is reason to believe that these eruptive spasms will continue and that we are now living in one of the quiet intervals." The Honolulu series vents are on Oahu east of Pearl Harbor, as was mentioned above under earthquakes possibilities.

The basalt forming the Kalaupapa peninsula and the tuff cone forming Mokuhooniki and Kanaha islands off the eastern end of Molokai are the only late eruptions there. Neither are very young, and therefore renewal of secondary volcanism is unlikely on Molokai. There are no secondary vents on Lanai, and so additional activity there is unlikely, too.

There are four secondary vents on West Maui, mainly lying near Lahaina, that erupted in Late Pleistocene or Recent times. Thus as was also noted for Honolulu, there is a chance of renewed activity on West Maui at some time in the next few thousand years.

On northern Hawaii there are no Late Pleistocene or Recent vents on Kohala. However, Mauna Kea has six small lava flows younger than its glacial deposits (Pleistocene age). These are near the summit, and the possibility of renewed volcanism there should have little effect on coastal areas.

Local Detailed Studies

Introduction. Certain factors were investigated thoroughly in areas that appeared to be able to provide some answers to such basic problems as rate of coral growth, nearshore circulation, and sampling error. A discussion of each follows.

La Perouse Bay, Maui. A detailed study of thickness and rates of growth of corals on the top of the historic lava flow near La Perouse Bay, Maui, is a contribution toward understanding the development of reefs and the production of some components of lime-sand in Hawaii. The field work was performed in the spring months of 1963 by B. L. Oostdam, Fellow at Scripps Institution of Oceanography and part-time research assistant at the University of Hawaii, and was supported in part by this shoreline research project. Oostdam attempted to obtain rates of formation of reef sediments and net growth rates of reefs on top of a lava flow which has been roughly dated by grandchildren of eyewitnesses and by other methods as having been formed about 200 years ago. Quantitative data in this time-range are lacking in the geologic literature, yet they would be necessary in any long-range evaluation of the nearshore sediment budget. Oostdam s work included determination of coral thickness by chisel and sledge-hammer, photography of reef zones, sediment collecting, and mapping the margins of the flow, to a depth of water of about 200 feet. Some of his preliminary conclusions, (Oostdam, 1963) are summarized here.

Near La Perouse Bay onshore sediment transport is small. Some sediment is lost to the offshore by slow creep and diffusion. Alongshore sediment transport is slight, with a net direction to the north, following the currents in the area, which are weak with a net set to the north. Four zones based on coral growth are: A. Barren zone (shallowest), B. *Pocillopora meandrina* zone, C. *Porites* I and II zone, and D. *Porites compressa* zone (deepest). In addition, and not dependent on depth, about 16% of the bottom remains uncovered volcanic rock and 24% is covered with sand and silt in pockets 1 to 2 feet thick. The median thickness for the most abundant coral, *Porites compressa*, is 2 feet, suggesting an average vertical net growth of about 1 foot per century. P. *compressa* is only found at depths between 10 and 90 feet, and is thickest (median 4 feet) at about 30 feet depth.

In plots from which several cubic feet of coral were removed and weighed, the *in situ* dry density of a reef of growing P. *compressa* is about 0.36 gm/cc, or 22.5 lb/cu.ft. After several assumptions, the average annual production of $CaCO_3$ in this reef area is determined as about 0.32 lb/sq. ft., of which roughly half remains as skeletal reef material, and half becomes sand.

Oostdam also summarized the literature pertaining to rates of growth of coral. Mayor s quantitative studies in Samoa (1924), involving entire reefs, and relating the rate of polyp-growth to rate of calcification, were an early important work. He found an integrated vertical growth of 8 mm (1/3") a year over an entire reef. Vaughan and Wells (1943) gave the ecological conditions favoring coral growth. Hawaii is on the fringe of the favorable belt.

Biological productivity of reefs has been measured by Sargent and Austin (1949, 1954) and Odum and Odum (1955) for Pacific atolls, and by Kohn and Helfrich (1957) for Kapaa, Kauai, and Gordon and Kelly (1962) for Mokuoloe (Coconut Island), Oahu. Kohn and Helfrich determined the gross primary productivity of Kapaa as 2,900 gm carbon/m^2/year. No attempt was made to separate carbon that entered living tissue from carbon that was becoming calcium carbonate.

Growth of individual coral heads has been measured in several localities. Edmonson (1929) found that 161 corals on Waikiki reef grew vertically an average of 12.9 mm (1/2") annually. Individual heads averaged over 100% annual increase in weight, and younger specimens grew faster.

Some important differences between reef growth in Hawaii and areas closer to the equator are the absence here of the genus Acropora, the dominant coral of atolls, and the lesser importance here, especially along leeward coasts, of coralline algae, the most wave-resistant growth of atoll reefs.

Waialae Beach Park, Oahu. Waialae Beach Park in Honolulu is fronted by a reef flat about 500 yards wide. Graduate student David Baver studied that reef-flat area in detail as a class project in a University course to determine the relationships between living plants and animals, the nearshore physical processes, and the components of the sediment.

The area is near the mouth of an intermittent stream, and a sand-bottomed channel about 6 feet deep in the reef-flat continues from stream mouth to the reef edge. A current usually flowed seaward out the channel. Sand samples from various stations on the reef flat and channel bottom were examined for living foraminifera that could be identified by an organic dye which stained the living protoplasm. Although both large foraminifera, mainly Amphistegina, Heterostegina, and Marginopora, and smaller foraminifera, such as Quingueloculina and Spiroloculina, are present as empty shells in the sediment, the preponderant bulk of the foraminifera contribution is from the larger-sized genera. Yet no living large foraminifera were found in the area. The smaller ones were rarely alive on the reef-flat, but were common in the sand-covered channel. It is concluded that the chief source of foraminifera, at least the larger ones that are so important volumetrically but do not thrive under the variable ecologic conditions of the reef-flat, must be by transport in from the reef edge.

Living mollusks and echinoids were rare on the reef flat, and there were no living corals there, except for some encrusting types near the reef edge. These elements of the sediment must also largely have been transported onto the reef-flat. Of potential sediment producers only the algae were common inhabitants.

The detrital sediment washed in by the stream is deposited initially near the stream mouth. A pile of mud two feet thick deposited in the channel head after one heavy rainstorm was later reworked by the waves and currents. In general, detrital sediment is concentrated in the channel, especially the finer grain-sizes, and moves seaward along it. Sediment is more than 5 feet thick in the channel, but only a few inches at most on the reef-flats.

The sediment budget for the reef at Waialae is therefore shown to include a source of detrital sediment at the stream mouth and sources of organic or carbonate sand chiefly from the reef-edge, but also partly from the reef flat, that is generally driven landward. Sediment, especially the fine sizes, that is trapped in the sand channel moves seaward along it.

Pokai Bay, Oahu. Pokai Bay on the leeward coast of Oahu was the subject of a detailed study of nearshore circulation, sediment movement, and sediment volume. Graduate students Robert Brown, J. F. Campbell, F. W. McCoy, Jr., and Gary Stice investigated the area as a class project in a University course, using supplies and equipment provided by this general shoreline project.

At Pokai Bay the general bottom configuration is a gentle slope of about 1 in 80 seaward from a crescentic beach about 1200 yards along the coast, as described in the section on 90 significant beaches in Hawaii. A 250-yard-wide channel with sandy bottom traverses the reef slope, trending west-southwest perpendicular from the middle of the bay and beach. Rocky points bound the bay, and from the southern one, Kaneilio Point, a breakwater is built northward protecting the small boat anchorage at the south end of the bay. The former nearshore circulation and sediment drift in the bay apparently was in the form of two eddies, generated by waves. The northern eddy moved clockwise; water and sand moved shoreward, then south along the beach to its middle and then seaward out the channel. The southern pattern was of water and sand moving shoreward, then north along the beach and then also seaward out the channel. The southern pattern was eliminated by the breakwater so that now some sand moves south past the channel head and is deposited in the harbor area, from which it must be dredged and trucked northward periodically. A groin constructed in mid-beach has had little success is stopping the drift.

Holes jetted by a SCUBA diver into the sand channel show the sand to be more than 15 feet in thickness, in contrast to scattered sand pockets a few inches thick over about 10% of the reef slope, and a discontinuous layer of sand one-grain-thick over most of the rest of the reef slope. From calculations of the volume of the sand there is at least four times as much sand stored in the offshore channel as is present on the whole beach. The sand on the reef slope does move shoreward, and the top layer of channel sand moves seaward.

Kapaa, Kauai. An investigation of the Kapaa area of windward Kauai was commenced by graduate student J. F. Campbell, but the period of his observations may last another year or more. Kapaa reef has been studied before a "swimming hole" was dredged in the reef near shore (Kohn and Helfrich, 1957; Inman, Gayman, and Cox, 1963). Campbell will describe the changes since then. Observations to date of the accelerated erosion at Kapaa suggest that sand, which normally was driven across the reef to nourish the beach, is now being trapped in the dredged pit so that the shore in the lee of the pit is being eroded without new sand added to replace that removed. The sand eroded from the shoreline is carried alongshore to the channel near the south end of the reef and then swept seaward. From the size of the trap and the rate of its filling by sand as measured against pegs driven into the walls of the pit, Campbell expects to be able to estimate the sediment supply across the reef for a length of coast per unit of time.

Kaneohe Bay, Oahu. An investigation by deep drogues of near-bottom currents along the deepwater channel of Kaneohe Bay, Oahu, was made by Dr. Shepard and his student early in the project. Under strong trade winds the surface waters move onshore but return seaward at depth, whereas the reverse circulation is true under strong kona winds. The deep currents measured, however, are of insufficient velocity to transport sand-size particles. Later sampling showed the bottom sediments to be mud, in contrast to sands and fine gravels in the offshore reef areas and muddy sands on the bay-fringing reef-flats. The offshore sand is therefore an isolated system, and is not a source for any nearby beaches.

Southeastern Oahu beaches. Sandy, Wawamalu, and Makapuu Beaches near the southeasternmost edge of Oahu were selected early in the project as the sites for a statistical study of sand-sampling on beaches. At Sandy Beach three or more samples were collected at even intervals along each of twelve traverses of the beach selected at random. Within a geomorphic division of the backshore, such as the berm or the backshore without berm, there was no significant difference of the parameters of median grain-size, sorting, and skewness of the samples. Similar results were obtained within seven traverses of Wawamalu Beach and within five of Makapuu Beach. Yet the parameters served to distinguish one beach from the other. It was concluded therefore that 99 sand samples of 100 selected at random within a geomorphic feature of the beach would represent the grain-size characteristics of the feature within the size limits of the sieves used to determine grain size. However, there were significant differences from feature to feature and from beach to beach. Because of these results we have a high degree of confidence that single samples collected from a beach feature, on our subsequent visits when measuring beach profiles, will characterize that beach.

RECOMMENDATIONS

Beaches and Coastal Defenses

The most accurate method of keeping areas of critical coastal erosion under surveillance is through continued periodic measurements along established ranges. The importance of beaches in the tourist economy and the recreational activities of local inhabitants should be sufficient reasons for maintaining surveys on a number of key beaches. These ought to include the important beach parks, the large calcareous beaches on the leeward sides of islands, beaches being exploited for sand, and beaches adjacent to marine engineering works.

Measurement of beach profiles ought to be at least semi-annual, i.e., in late winter and in late summer, if not quarterly. In addition, measurements should be made after any tsunami.

The present study has indicated several lines of additional research that ought to be pursued. An outstanding example is the sand content, dynamic processes, and geologic history of the sand-bottomed channels crossing many of the reefs. Also, the ecology of local foraminifera should be studied more closely, because of their importance in the composition of most calcareous beaches. In fact, the entire problem of nearshore ecology, especially polution, needs greater study. What are the effects of our overflowing cesspools in coastal areas? In passing, we might ask why septic tanks, commonly more sanitary and/more easily constructed than cesspools, are not used in areas without sewer lines?

More basic information on the distribution of wave heights, periods, and directions of approach is necessary before sophisticated work is possible on wave energy on beaches. Additional effort ought to be placed on investigating local areas of apparently very high production of sand, as at Kaneohe Bay barrier reef, Oahu, and near Moomomi, Molokai.

Sand is necessary for a number of construction purposes. Its chief local use is as a component of concrete, but it also is used in mortar and as a drainage course under paving. Local sands are not useful in foundry work, glass making, or as abrasives. River sands are almost non-existant in Hawaii, and sand manufactured by crushing basalt rock needs thorough washing and screening. Most Hawaiian beach sands behave in an excellent manner when used in concrete. Undoubtedly beach sand will be used in the future for Hawaii's construction needs, but care should be exercised that removal in any one place does not exceed the normal supply there. Sand dredges should be placed at the down-drift ends of beach circulation systems to obtain sand that otherwise would be lost naturally.

The use of sand which is already out of the beach system should be encouraged. A thorough study of the sand-channels across Oahu's reefs would indicate whether they are acceptable sources. Sand dredged and pumped onto a barge for transportation ought to be economically competitive with beach sand trucked away. The submarine area of several square miles northwest of Barking Sands, Kauai, ought to be mapped as a possible ultimate sand reserve. Some research there by Scripps Institution marine geologists is as yet unpublished. The Kaneohe Bay sand flats need additional study. Sand can be removed safely from dunes if a sufficient beach and dune buffer zone is left between the sand-pit and the ocean. Dunes that act as a protection to inhabited lowlands from storm waves and small tsunamis, as at Maili, Kailua, and Waimanalo, Oahu, and near Kahului, Maui, should not be exploited. Engineering research is needed on the washing of dune sands that may be dirty from organic material, from interbedded alluvium, or from wind-blown dust.

Fortunately for Hawaii, engineers of both the Harbors Division of the Department of Transportation and the local district of the U. S. Army Corps of Engineers are aware of our problems of beach erosion and are attempting to establish adequate measures of coastal defense and to re-establish some beaches now badly eroded. As a fundamental matter of policy, all responsible agencies should recognize that the best defense of any coast is a stable and wide beach, and preferably one with dunes behind it. Dunes act as a secondary sand defense. Any artificial defenses should have the primary aim of stabilizing, even increasing, sandy beaches. In every case before a seawall is built the relative costs of the property to be protected and of the wall itself should be weighed against the fact that many seawalls increase the destructive character of certain waves and most seawalls inhibit the growth of normal beaches and dunes. For structures perpendicular to the shore, several small groins usually are more effective than a jetty or a few large groins in trapping drifting sand. Some sand must be able to move past the groin to nourish the beach down the direction of the drift. Many types of vegetation aid in trapping sand on dunes, and such vegetation should be encouraged. Sand that blows inland beyond dunes is wasted.

An attempt should be made to identify a number of potential donor beaches that might be used to replenish the sand on eroded ones which are especially useful to man. Sand sampling and analysis differ, in this situation, from most of the tests performed on building materials, and stress grain-size analyses of undisturbed samples at random locations within the sand body.

The donor sand should be both slightly coarser and better sorted than the sand on the eroding beach.

Marine Work

Perhaps the best introduction to this section on coastal engineering works is a quotation from the Dutch coastal engineer, Schiff, who said, "Be sure to put off until tomorrow what you do not absolutely have to do today." This remark is partly a warning on any attempts to change nature in the nearshore environment and partly a warning that thorough investigations of the local marine geology are needed covering all seasions. Probably only in dam site investigations has a greater proportion of the total cost of a structure been properly assigned to the preliminary investigations, and has insufficient research resulted in so many failures. As also mentioned above under coastal defenses, the State Harbors Division and the Corps of Engineers share responsibilities over marine works in Hawaii. Because of their ultimate responsibility for the effectiveness of works built, these agencies should be supported in their demands for complete and detailed site investigations, and not pressured unduly for hasty, makeshift structures that are poorly situated.

Natural Disasters

Historically, Hawaii's greatest problem of disasters in shoreline areas has been the tsunami, and probably it will continue to be so. The State ought to maintain an active interest in warning and evacuation procedures, education of the public, and study of the fundamental behavior of these waves.

The State and County Civil Defense organizations, as well as newspapers and radio stations, have been utilizing the potential inundation limits drafted by the Tsunami Research Program of the Hawaii Institute of Geophysics. Further research from an architectural engineering standpoint might lead to a realistic building code in tsunami-prone areas.

Flood control in coastal areas is certainly to be desired. However, methods chosen should be ones that do not upset the balance of other dynamic forces in shoreline areas. Two examples should suffice. In coastal Southern California numerous small check-dams in the mountains have strongly reduced the hazards of flash floods after abnormal rains--but they also trap sand that might otherwise nourish the local beaches. The dams have been indited as the cause of accelerated beach erosion from Ventura to Newport. Waimea River on Kauai and a few other rivers in the State supply large amounts of sand during floods, and in those places the potential value of flood control must be weighed against the potential loss of value from eroded shores. Fortunately, many local beaches are highly calcareous, and not dependent on river-transported detritus.

On windward Oahu a few years ago a real-estate developer agreed to keep the entrance of the stream draining Kaelepulu Pond open, thus, reducing materially the risk of flooding his homes there and he was allowed to utilize as he wished the barrier-beach sand so removed. Of course the natural wave energy and alongshore drift continued to move sand into the pit where the dredge was operating, until nearby residents, becoming alarmed at the extent of local beach erosion that resulted, took action.

Loss of some property in shoreline areas to lava flows and, to a lesser degree, to earthquakes, will without question continue. Dr. G. A. Macdonald pointed out, as he has also done in the past when questioned by chambers of commerce or real-estate developers, that even though these events are spectacular, their frequency of occurrence in a specific locality is low. A useful study, he believes, would be a comparison of eruption losses to such other hazards as loss by fire or by termites and decay in equivalent areas of Puna, Kau, and Kona and for equivalent lengths of time.

Loss of property owing to landslides has forced Los Angeles to require site investigations by a qualified geologist before issuance of building permits. As the urbanization of Oahu continues, with many new houses and roads built on steep slopes, prudence may indicate Hawaii's need for a similar law.

State Geological Survey

No obvious agency exists to initiate the studies listed above or to coordinate the results of this report or any later studies with any concerned public or private undertaking. A final suggestion, therefore, is that a State Geological Survey be established.

Hawaii is one of the three states that are without a state geological survey. Such organizations range from complexes of hundreds of geologists, engineers, and clerks in the larger states having important natural mineral resources and major engineering problems, to a handfull of part-time employees or consultants in some of the smaller states. Fortunately for Hawaii, there has been scientific counsel for the single most important geologic resource in these islands, the Oahu ground-water supply, and the U. S. Geological Survey has maintained a strong interest in the water resources of the Islands. Useful and interesting research into geological problems has been conducted by private agricultural associations, the military, and several State agencies including the University of Hawaii. Yet there has been no single office responsible to give local geologic advice to the public and to engage in, or coordinate, research in those areas in which existing public or private groups have neither the motivation nor the ability to act.

<u>Specific Recommendations</u>

In summary of this section, we hereby recommend:

1. Continuation of seasonal profile measurements on selected important beaches in the State.
2. Initiation of detailed research into these topics:
   a. Sand-bottomed channels that cross Hawaiian reefs
   b. Ecology of foraminifera and other local reef-inhabiting organisms, especially in regard to polution by man
   c. Local wave statistics
   d. Areas of high sand productivity in Hawaiian waters
   e. Actuarial research into the specific risks of volcanic and earthquake disasters in Hawaii
3. Control of the location and intensity of beach-sand exploitation.
4. Encouragement, through zoning and research, of the exploitation of dune and offshore sand as a substitute for beach sand.
5. Encouragement of the stabilization of existing beaches and dunes.
6. Identification, before actual need, of potential donor beaches.
7. Requirement of thorough preliminary investigations before commencement of marine engineering works.
8. Continued support of State, Federal, and University agencies with responsibilities in shoreline research and development.
9. Establishment of a State Geological Survey for the coordination and the initiation of geologic research and engineering counsel.

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The second edition of the first text on marine geology in the western world. Topics include methods, instrumentation, ocean waves and associated currents, catastrophic waves, ocean currents, physical properties of sediments, mechanics of sedimentation, classification of shorelines and sea coasts, beaches, shore processes, the topography, sediments, origin, and history of continental shelves and continental slopes, submarine canyons, coral and other organic reefs, the topography, sediments, and stratigraphy of the deep oceans, origin and history of ocean basins, mineralogy and chemistry of marine sedimentations; and an extensive bibliography (chiefly since 1943).

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Simply-written account of the salient geologic features and histories of all the islands.

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Includes sections on coastal geomorphology, late Pleistocene dunes and reefs, and recent beaches.

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Present data are inadequate to determine practical engineering minimization of danger to life and property in Hilo. Hydraulic model studies, observations of long-wave behavior in the bay, historical and statistical studies, and economic and planning studies are recommended.

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Studied in laboratory with various widths and slopes of channel across reef.

Trask, P. D., 1955, Movements of sand around Southern California promontories: Beach Eros. Board, Tech. Memo. no. 76.

Sand moves in three ways: along the beach and surf zone, in the water to 30 feet, and from 30 to 60 feet. Little sand movement deeper than 60 feet.

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Periodic measurements and sampling along profiles showed most beaches with fine sand, and building berms, in summer and fall, and with coarse sand and eroding in winter and early spring.

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A synthesis of the major geologic processes, taking into account the data from marine geology and volcanism discovered to that date.

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Most recent (mid-1963) general synthesis of theories of reef and atoll formation in relation to their environment.

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Emphasis on available water supplies and on geomorphology.

__________, 1926, Pyroclastic geology of Oahu: B. P. Bishop Mus. Bull. 30, 121 p.

The geology of the tuff cones near Honolulu, all of which are in coastal areas.

__________, 1927, Estimates of marine and fluvial erosion in Hawaii: Jour. Geology, v. 35, p. 117-133.

Total marine erosion in Hawaii is about one-seventh the fluvial total, from rate relationships deduced between the two.

__________, 1928, Principles of stream erosion in Hawaii: Jour. Geology, v. 36, p. 385-419.

Palis and steep-walled valleys are due to normal erosional processes in this region of porous rocks that weather easily, slight temperature range, and high rainfall in mountains.

__________, 1938, Marine bench-forming processes, I, water-level weathering: Jour. Geomorph., v. 1, p. 5-32.

Four processes of marine bench-formation in Hawaii, where tides have a low maximum range. These are (1) water-level weathering, (2) solution benching, (3) ramp abrasion, and (4) wave quarrying. Water-level weathering is most effective in tuffs and weathered basalts.

__________, 1939, Marine bench-forming processes, II, solution benching: Jour. Geomorph., v. 2, p. 3-25.

Importance of solution in forming marine terraces in limestone. Examples and illustrations chiefly from Oahu.

__________, 1943, Soil avalanches in Oahu, Hawaii: Geol. Soc. America, Bull., v. 54, p. 53-64.

Soil avalanches are an important means of denudation in the steeply-walled valleys of Hawaii. They resemble debris slides, but remove only soil, not soil and bedrock.

__________, 1949, Directional shift of trade winds at Honolulu: Pacific Sci., v. 3, p. 86-88.

A gradual shift in the direction of the prevailing surface wind at Honolulu, from about 044° in 1905, to 087° in 1927, to 089° in 1937, to 064° in 1946. A 45-year cycle is suggested.

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A marine bench 4 to 12 feet above sea level has been found on several North Pacific islands, indicating a drop of sea level of 12 to 15 feet.

__________, and others, 1961, Feasibility of a lava-diverting barrier at Hilo, Hawaii: Pacific Sci., v. 15, p. 352-357.

A downslope diversionary barrier is held to be unrealistic.

Zerbe, W., 1953, The seismic sea wave warning system: U. S. Coast and Geod. Survey, Jour., v. 5, p. 132.

A tsunami warning system is operated by the Honolulu Observatory of the U. S. Coast and Geodetic Survey. It depends on seismic information from here and elsewhere, and tide-gage information from stations near the earthquakes.

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